Naval Command,
Control and Ocean
Surveillance Center RDT&E Division San Diego, CA
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Technical Report 1525
November 1992

Advanced Unmanned Search System (AUSS) Testbed

FY 1987 Development Testing

J. Walton

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NRaD

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NAVAL COMMAND, CONTROL AND OCEAN SURVEILLANCE CENTER
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ADMINISTRATIVE INFORMATION

The work was performed by members of the Ocean Engineering Division (Code 94), Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA 92152-5000, under program element 0603713N, project S0397. The work was performed for Commander, Naval Sea Systems Command, Code 05R, Washington, DC. This report summarizes the work which resulted in the FY 1987 Advanced Unmanned Search System (AUSS) demonstration in July 1987.

Further information on AUSS is available in related reports that represent NRaD efforts through FY 1992. The bibliography is found at the end of this report.

Released by
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SUMMARY

OBJECTIVE

Describe the FY 1987 Advanced Unmanned Search System (AUSS) sea tests, including the modifications and improvements, made to collect data needed to support the next-generation system design.

RESULTS

The following subsystems were tested and evaluated: acoustic link, acoustic tracking, vehicle navigation, vehicle controls, sensors, computers, and search capability.

CONCLUSIONS

The AUSS vehicle was successfully tested and evaluated. In the process of this testing, many lessons were learned that will benefit future AUSS sea tests and the next-generation system design.

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INTRODUCTION

The Advanced Unmanned Search System (AUSS) program at the Naval Command, Control and Ocean Surveillance Center, RDT&E Division (NRaD), (formerly the Naval Ocean Systems Center [NOSC]) was sponsored by the Naval Sea Systems Command, Code 05R. AUSS fielded a testbed (or prototype) untethered supervisory control vehicle with an acoustic communication link. This effort supports the development of technology aimed at significantly improving the Navy's ability to conduct search in the deep ocean.

The AUSS testbed (also called prototype system) (figure 1) consisted of an untethered vehicle, a launch and recovery ramp, a maintenance van, an operations van, and the external acoustic relay system (EARS). The vehicle as shown in figure 2 was composed of search sensors, propulsion, energy source, electronics, mechanical, structural, and computer subsystems.

In an operations area nominally 2500-feet deep, 89 dives were conducted with the AUSS testbed. Of these, 71 dives were completely untethered. The first series of 18 dives were conducted with a mechanical strength member tethered to the vehicle to assure recovery. The next series of untethered tests involved developing and improving operational aspects, sensor performance, vehicle control, and software. Appendix A is the dive history for FY 1985. Appendix B is the dive history for FY 1986.

In FY 1987, tests conducted with the AUSS vehicle focused on defining, and solving technical problems and performance risks. Appendix C is the dive history for FY 1987. This report describes these FY 1987 tests, including the modifications and improvements made to collect data required to support the next-generation system design. Appendix D is a sample of the daily test plan and report for the FY 1987 tests.

OBJECTIVES

Several objectives were defined for the FY 1987 AUSS testbed sea tests, and were part of the AUSS Daily Test Plans and Reports. In summary, the primary objectives of the FY 1987 sea tests were:

ACOUSTIC LINK (AL)

Evaluate performance of AL system.

Predict performance of AL system at design depth.

Define deficiencies in AL system.

Design, build, test solutions to AL deficiencies.

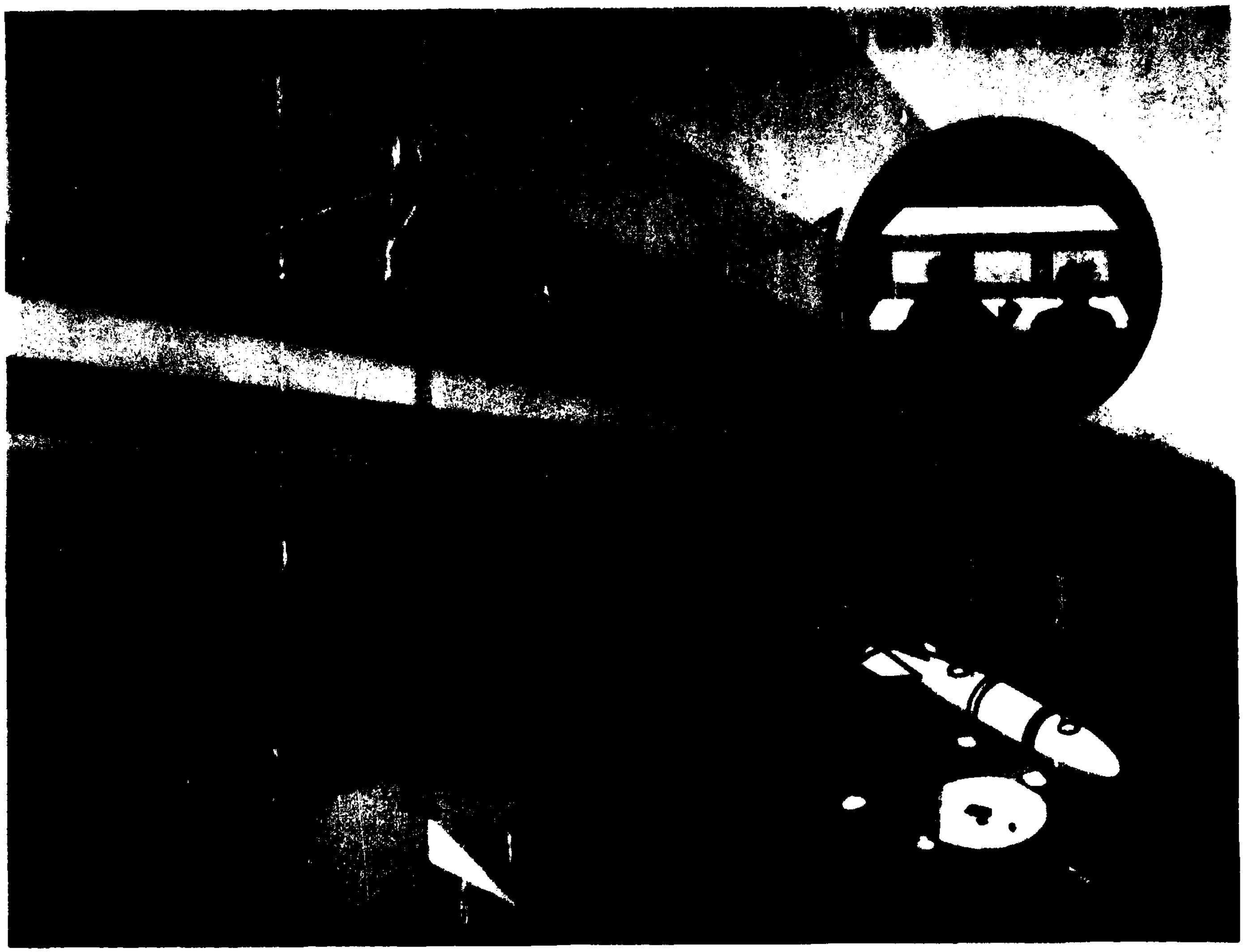

Figure 1. AUSS testbed.

AUSS Prototype Vehicle

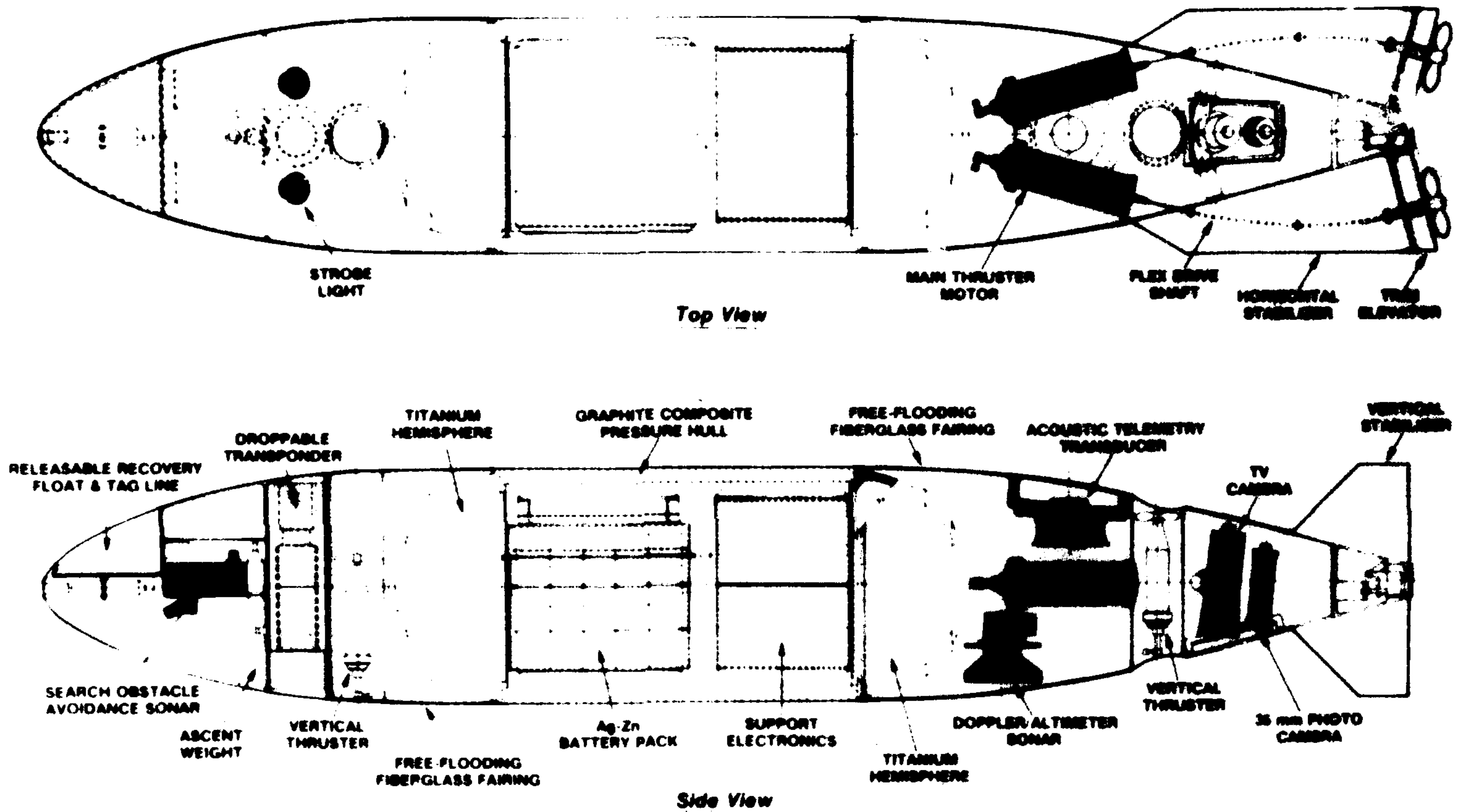

Figure 2. AUSS vehicle.

ACOUSTIC TRACKING (AT)

Evaluate performance of AT system.

Predict performance of AT system at design depth.

Conduct tests to define deficiencies in the AT system.

Design, build, test engineering solutions to the AT system.

VEHICLE NAVIGATION

Evaluate vehicle navigation system performance.

Conduct tests to define deficiencies in vehicle navigation.

Design, build, test engineering solutions to the navigation system.

VEHICLE CONTROLS

Exercise and improve AUSS vehicle control systems.

Conduct obstacle-avoidance maneuvers with AUSS vehicle.

Select maneuver best suited for AUSS obstacle avoidance.

SENSORS

Evaluate and improve the performance of AUSS search sensors.

COMPUTERS

Test and improve AUSS testbed vehicle computer hardware and software.

Test and improve AUSS surface computer software.

SEARCH CAPABILITY

Conduct a search demonstration with the AUSS testbed vehicle.

APPROACH

To meet the objectives of FY 1987 AUSS sea tests, a support platform, the motor vessel *Jamie G*, was contracted through the Military Sealift Command (MSC) and outfitted by NOSC with the AUSS testbed operations equipment. The AUSS testbed operations equipment consisted of an untethered vehicle, a launch and recovery system, the external acoustic relay system (EARS) towed fish, the EARS tow cable, the EARS winch, a maintenance van, a control van, a spares van, and auxiliary deck equipment.

For each sea test, a Test Plan and Report was prepared prior to the testing, and edited and completed during the course of the test deployment on the *Jamie G* (appendix D is an example). These reports identified the personnel involved in the testing, the conditions under which the tests were conducted, the objectives of the specific test dive, problems encountered during the dive and sea trip, results of the testing, and tasks requiring completion prior to the next test dive with the AUSS. These documents were prepared just prior to the sea trips to benefit from all lessons learned from previous trips. They were completed immediately following the sea test to assure freshness and accuracy of the information, and to assure that tasks leading up to following dives were embarked upon as soon as was possible.

The at-sea test team consisted of engineers and technicians well versed in the AUSS system and AUSS technology, and was composed mostly of AUSS design team members. This allowed for valuable at-sea re-engineering, repairs, and work-arounds to optimize the use of the vehicle.

The AUSS testbed vehicle was modified using "quick fixes" in an effort to speed turnaround in answering technical and performance questions. Modifications were made to various subsystems at the expense of the performance of other subsystems. Tradeoffs were made in subsystem performance to best utilize the vehicle to work on technical risk areas.

SUBSYSTEMS TESTS, EVALUATION, AND IMPROVEMENTS

The FY 1987 AUSS sea tests focused upon defining and solving technical and performance-risk areas. This report covers the most critical risk areas that were handled in FY 1987. The areas covered here are the acoustic link, acoustic tracking, vehicle navigation, vehicle control, obstacle avoidance, search sensors, and system computers.

All AUSS surface and underwater subsystems were used to perform the FY 1987 tests. Improvements were made in several subsystems, but not all changes are covered in this report. The total scope of all subsystem tests, evaluations, and improvements are covered in the FY 1987 daily test plans and reports (appendix D is an example).

ACOUSTIC LINK

System Description

The AUSS acoustic link (AL) is used to transmit system commands to the AUSS vehicle from the surface craft, and status information and sensor data to the surface craft from the vehicle. This acoustic signal transmission scheme allows the vehicle to operate free of any mechanical connection to the surface.

The surface AL and vehicle AL systems have modulators, demodulators, and transducers that transmit the acoustic signals through the water. The AL topside computer interfaces the AL system with the surface console computer, and the AL vehicle computer interfaces the AL system with the vehicle sensor computer. (See figure 10 for system computer block diagram.)

Status information and digitized sensor signals are modulated on two independent sidebands. The two sidebands (centered around an 11-kHz carrier) can be modulated with either identical (dual) data or exclusive (independent) data. The lower sideband (8–11 kHz) and the upper sideband (11–14 kHz) can each carry 1200 or 2400 bits per second (bps). The dual sideband operation provides data transmission redundancy, and the independent sideband transmission allows higher transmission rates (i.e., 4800-bps total for independent 2400-bps sidebands).

History

The acoustic link (AL) for the AUSS was first developed at NOSC and tested on the Benthic Untethered Multipurpose Platform (BUMP) in 1981. The acoustic link was able to transmit 4800-bps data with a bit-error rate of 10^{-6} to the surface ship during the BUMP testing. The surface ship was located above the BUMP within the projection of an upward-directed cone (apex at BUMP) with a 45° half-angle. The deepest depth for which this performance was demonstrated was 15,000 feet.

For the BUMP experiments, a special baffle was developed at NOSC and integrated with the BUMP transmit/receive AL transducer to produce an up-looking hemispherical beam pattern. The baffle used air-filled aluminum spheres in a matrix around the transducer that acted as acoustic reflectors. This development was necessary since there was no other existing technology available to accomplish the deep-ocean acoustic baffling. Early AUSS tests used the BUMP baffle. The original BUMP AL system design (with minor improvements) was used throughout the AUSS prototype testing.

The surface AL transducer was baffled with wet suit rubber and suspended from the stern of the support ship during the BUMP operations. The ship was restricted to drifting with this suspended transducer. The AUSS acoustic short baseline tracking system

required a stable surface platform, and the ability to transit with the surface platform was desired. A concept was developed to house both the acoustic-tracking transducer and the AL transducer in a stable towed fish.

The stable towed fish concept evolved into the external acoustic relay system (EARS). For the prototype, EARS was a stable fish towed behind a heavy depressor clump. The fish and clump are towed at a depth of 150 feet below the ocean surface. The performance of the acoustic link system on AUSS was not up to the BUMP standard of 10^{-6} bit-error rate at 4800 bps throughout the 45° half-angle cone above the vehicle. The beam pattern appeared to have "holes" (regions of very-high -error rates), and the average bit-error rate across the beam at both 4800 bps and 2400 bps was worse than the BUMP standard. Further, measurements of noise in the vehicle acoustic link system showed that the signal-to-noise ratio (SNR) on the vehicle at 2500 feet was near the operational limit, and operation at greater depths was not possible without significantly reducing vehicle noise levels.

At-sea measurements showed there were frequency-selective fades (in the range of the carrier frequency) dependent on relative ship/vehicle position. Surmising the beam pattern was affected by a defective baffle, the BUMP baffle and transducer were tested for beam pattern at NOSC's Transducer Evaluation Center (TRANSDEC). After verifying the problem (many of the spheres had filled with water) and futile efforts to "patch" the baffle, a new baffle was constructed.

The new baffle tested satisfactorily at TRANSDEC and, although the fade problem was corrected, error-rate performance showed little improvement. Error-rate performance was still position-dependent.

FY 1987 Acoustic Link Beam Pattern Tests

Tests were structured and conducted at-sea in an effort to characterize the beam pattern of the new AL transducer baffle. The AUSS vehicle was commanded to "hover" at a constant depth and heading, and repeatedly transmit sonar data or video pictures to the surface ship. The ship ran patterns above the vehicle, and the vehicle heading was changed from time to time. Figure 3 is an example of a ship position plot obtained using SEATRAC/Mini-Ranger navigation (an integrated navigation system) during these experiments. Transmission-error rates were determined from the operator's video screen by counting the number of blank video lines in sensor images and by counting the lines that had check-sum errors flagged during their reception.

During these tests, the AL transducer/baffle was operated in a position above the vehicle. The baffle was elevated in an effort to eliminate shading of the acoustic beam by the vehicle pressure vessel and other equipment. The elevated position improved the performance of the AL, but problems still existed.

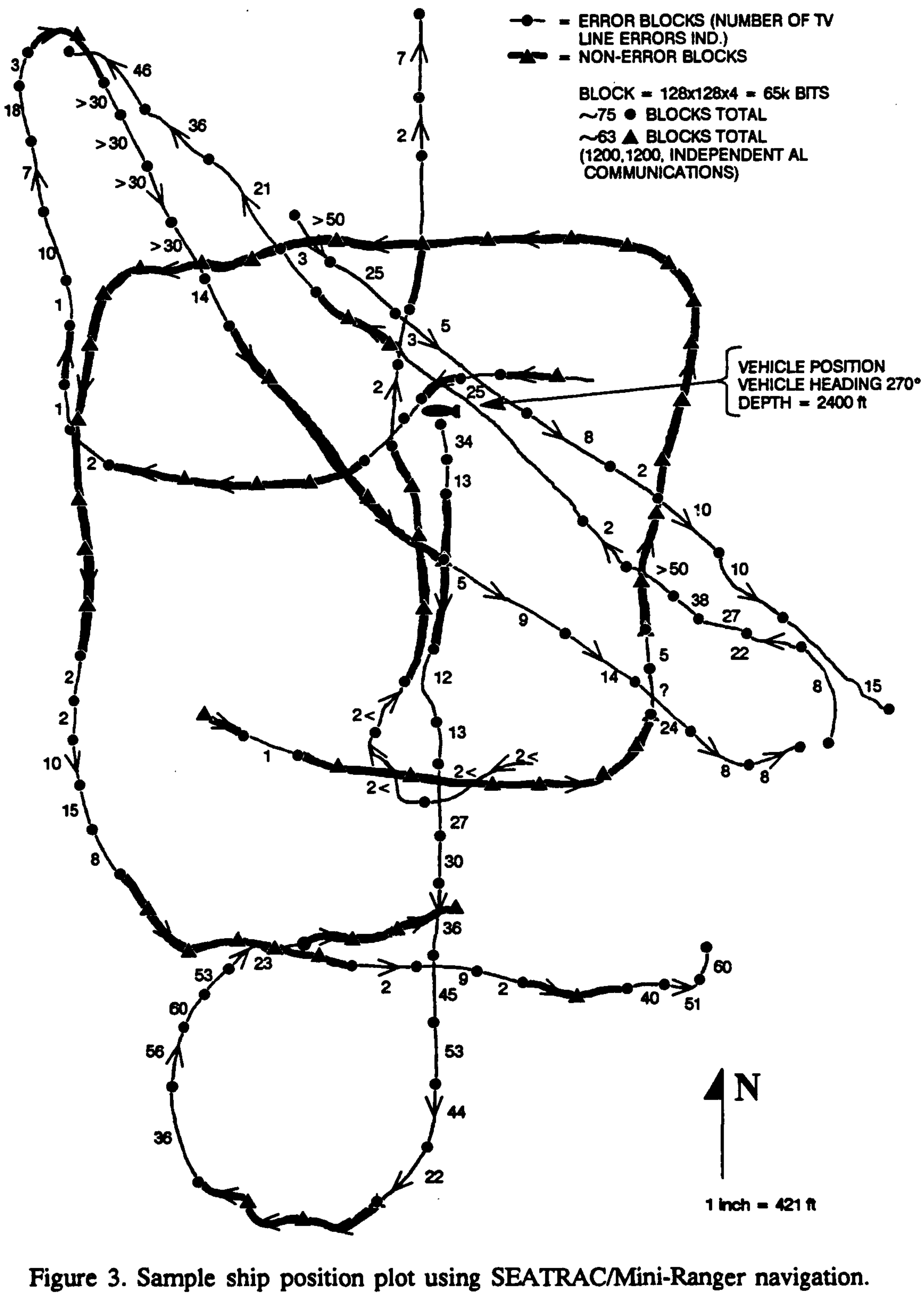

Figure 3. Sample ship position plot using SEATRAC/Mini-Ranger navigation.

The 11-kHz AL carrier frequency and the 8- and 14-kHz sideband frequencies were observed on an oscilloscope during the experiments. Very little fade was observed. Evidently a major source of AL performance degradation still remained. This performance degradation and the solutions are discussed in later sections of this report.

FY 1987 EARS Clump Tests

During the beam pattern tests, it was noted when the ship was traveling toward or away from the position of the AUSS vehicle, the error rate in the AL system increased. This observation led to a theory that there was a beam pattern problem in the EARS fish AL transducer/baffle. If the beam pattern from EARS was being shaded fore and aft by the EARS fish, it would account for the degraded performance.

To test this theory, a transducer with baffle was mounted on the EARS depressor clump, which is a weighted undersea mass used to depress the EARS tow cable. The clump transducer was wired such that the surface AL transmit/receive function could be switched between the EARS transducer and the clump transducer.

Two important observations were made during the clump AL transducer tests. Operation of the AL from the clump did not improve the performance of the AL, and operation of the AL from the clump did not degrade the performance of the AL. The first observation dispelled the fore/aft shading theory, and the second observation indicated that the EARS fish may not be needed to operate the AL.

The clump transducer was left in place and used successfully for most of the balance the FY 1987 sea tests.

FY 1987 Acoustic Link Doppler Shift Tests

More at-sea tests were conducted with AUSS stationary and the ship moving. For these tests the AL-carrier frequency was observed for Doppler shift. There was a good correlation between high-error rates and small Doppler shift in the AL-carrier frequency. The point at which the AL system was affected was at a carrier Doppler frequency shift (3.8 Hz) corresponding to a relative velocity between the ship and the vehicle of 1 knot.

Tests were conducted in the laboratory to confirm the existence of a problem with the Doppler shift. The Doppler shift was simulated in the lab by playing a tape recording of AUSS AL transmissions into the AL demodulator and varying the speed of the tape recorder. The simulation verified that the problem was indeed a result of Doppler shift.

A "software fix" was developed for the AL Doppler shift problem. This fix used on-hand data acquisition cards interfaced with the IBM computer. Due to hardware limitations, Doppler correction could only be made in a playback mode after acquiring a

single frame of video from one sideband. The video frames were simultaneously fed into the Doppler corrector and displayed on the operator video screen. The Doppler-corrected video was later displayed for comparison. All the errors noted on the operator screen for data transmitted at 1200 bps were eliminated by the Doppler corrector except for cases when the ship was directly over the vehicle.

A realtime AL Doppler correction technique was designed and implemented in the AUSS surface system. This was done to improve the AL performance for future search performance demonstrations, and to provide a better environment to investigate the remaining AL performance deficiencies. The realtime technique used hardware only. The main component of the hardware Doppler corrector is a first in first out (FIFO) discrete circuit. The digitized AL signals were stored in the FIFO at the Doppler-shifted AL-carrier frequency and read out into the AL system at the correct rate (11 kHz). Using this technique, all errors were corrected at 2400 bps (except when directly over the vehicle) and the performance at 4800 bps was improved to the quality of previous 2400-bps transmissions. The approximate bit-error rate calculated for 2400-bps transmissions (include data collected directly over the vehicle) was 10^{-5}. For 4800-bps transmissions, the calculated bit-error rate was 10^{-3}.

FY 1987 Acoustic Link Reverberation Tests

The realtime Doppler-corrected AL allowed a closer look at the performance degradation directly above the vehicle. The vehicle was fitted with an additional transducer on its tail that extended beyond the main thrusters. This transducer was not baffled and was omnidirectional. The capability to switch the AL function between the additional transducer (dubbed the "stinger") and the existing baffled transducer was implemented. The ship was steered in patterns that ran directly over the vehicle while the vehicle generated 12-kHz pulses projected either by the AL transducer or the stinger.

The EARS clump transducer was used to receive the signals from the vehicle. Reverberations at 13 to 14 dB down from the direct path were observed for both the AL and stinger transducers. The reverberations in the AL transducer transmissions occurred immediately after the direct path (figure 4) and appeared to be reverberations internal to the baffle and the vehicle structure around the transducer. The reverberations in the stinger transducer transmissions (figure 5) were further delayed and appeared to be reflections from the ocean bottom. Acoustic link-error-rate performance over both transducers was approximately equal.

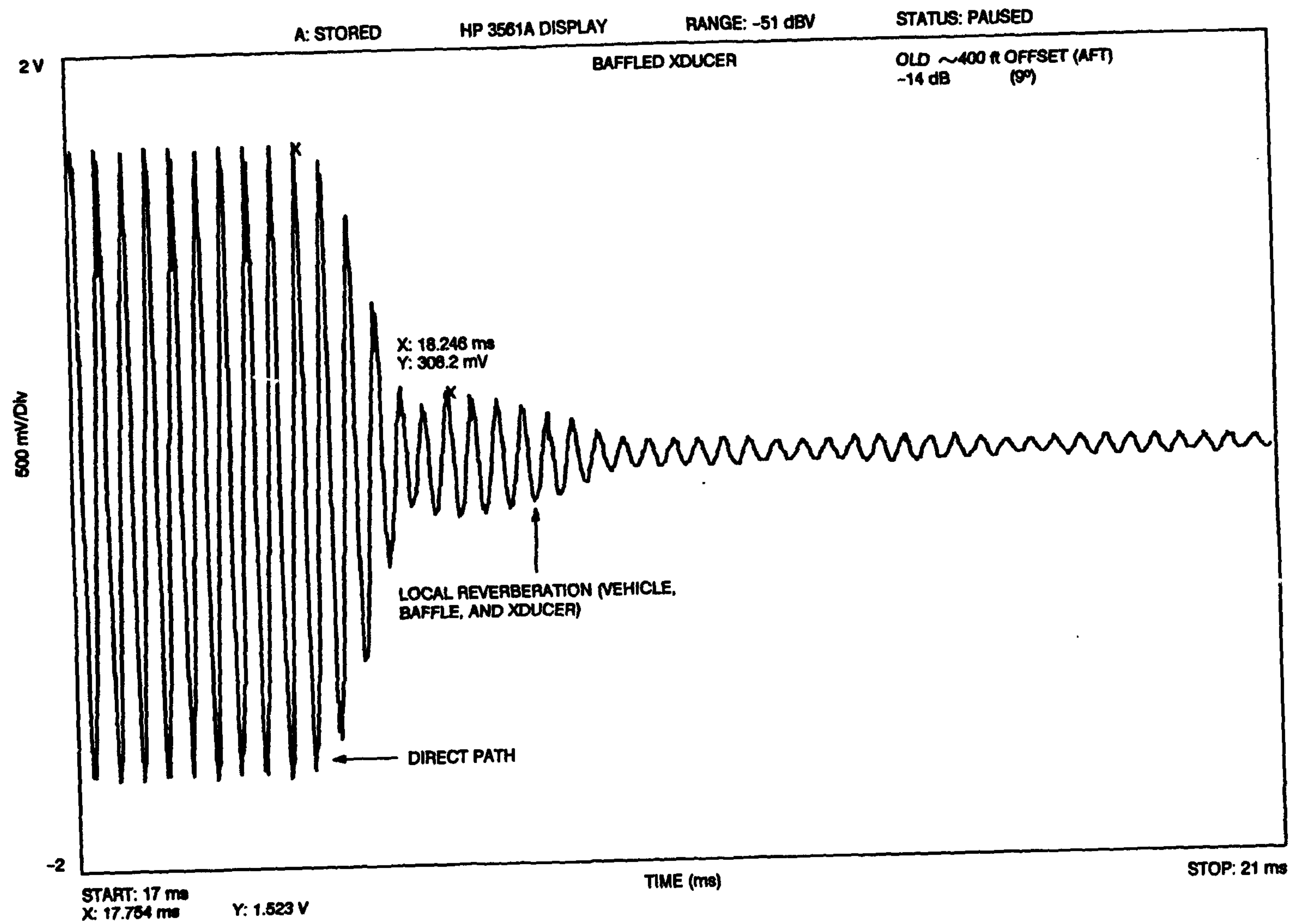

Figure 4. Reverberations in AL transducer transmission immediately after the direct path.

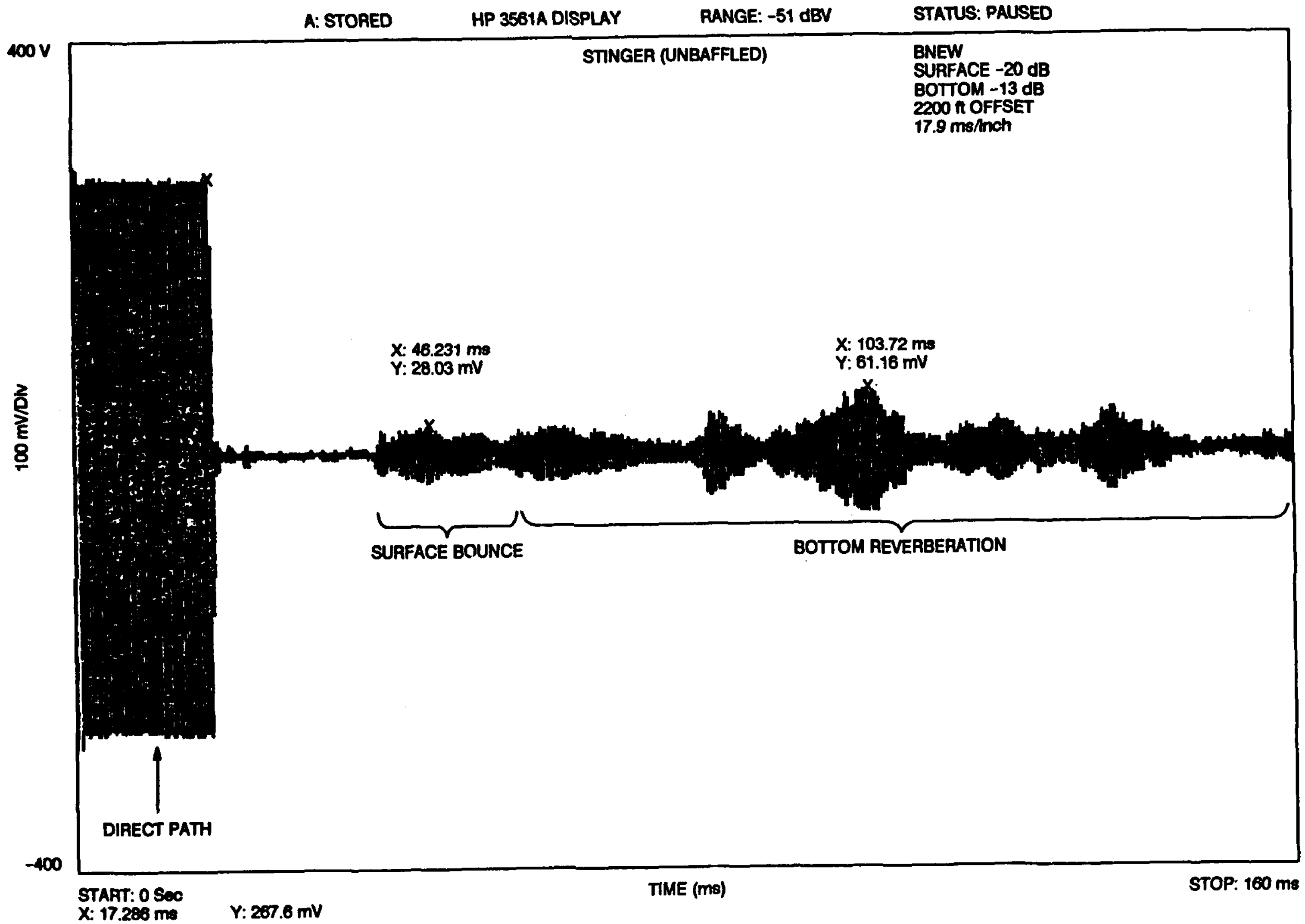

Figure 5. Reverberations in stinger transducer transmissions.

The vehicle was taken to TRANSDEC to investigate the reverberation problem further. The vehicle was moored to the bottom and was not powered. Pulses were sent to the AL transducer through a wire from the surface. The transmissions were received by a near-surface transducer and observed on an oscilloscope. The reverberation problem was re-created for transmissions received directly over the vehicle. Also observed was significant pulse degradation. Figure 6 is a typical plot taken with this configuration at TRANSDEC.

The AL transducer assembly including the transducer, the baffle, and the mounting plate were removed from the vehicle and mounted separately on a pole. Pulses were transmitted and received as before. Some "ringing" still existed. There was less pulse degradation than in the vehicle-mounted configuration (figure 7).

Removal of the mounting plate from the transducer assembly reduced the duration of the ringing (figure 8) when operated in the pole-mounted configuration. Removal of the baffle from the assembly nearly eliminated the ringing (figure 9).

FY 1987 Acoustic Link Noise Tests

At-sea measurements of the noise were taken in the AL system on board the AUSS vehicle and stored in its bubble memory "flight recorder." These data were later transmitted to the surface via the AL and analyzed. The noise was determined to be at acceptable levels as long the thruster motors were not running.

Several noise-reduction "quick fixes" were developed and installed, however, the SNR was not improved. These fixes included several rewiring efforts, filtering, and mu-metal shielding.

Dockside tests were conducted to determine whether the thruster noise source was acoustic or mechanical noise created by the propulsion system drive train. A separate transducer was placed in the water to listen for the acoustic signature of the vehicle with the thrusters running. Noise levels measured by this transducer were small with respect to the noise in the acoustic link system. This led to the conclusion that the noise in the acoustic link system was electrical noise from the motor controller circuitry.

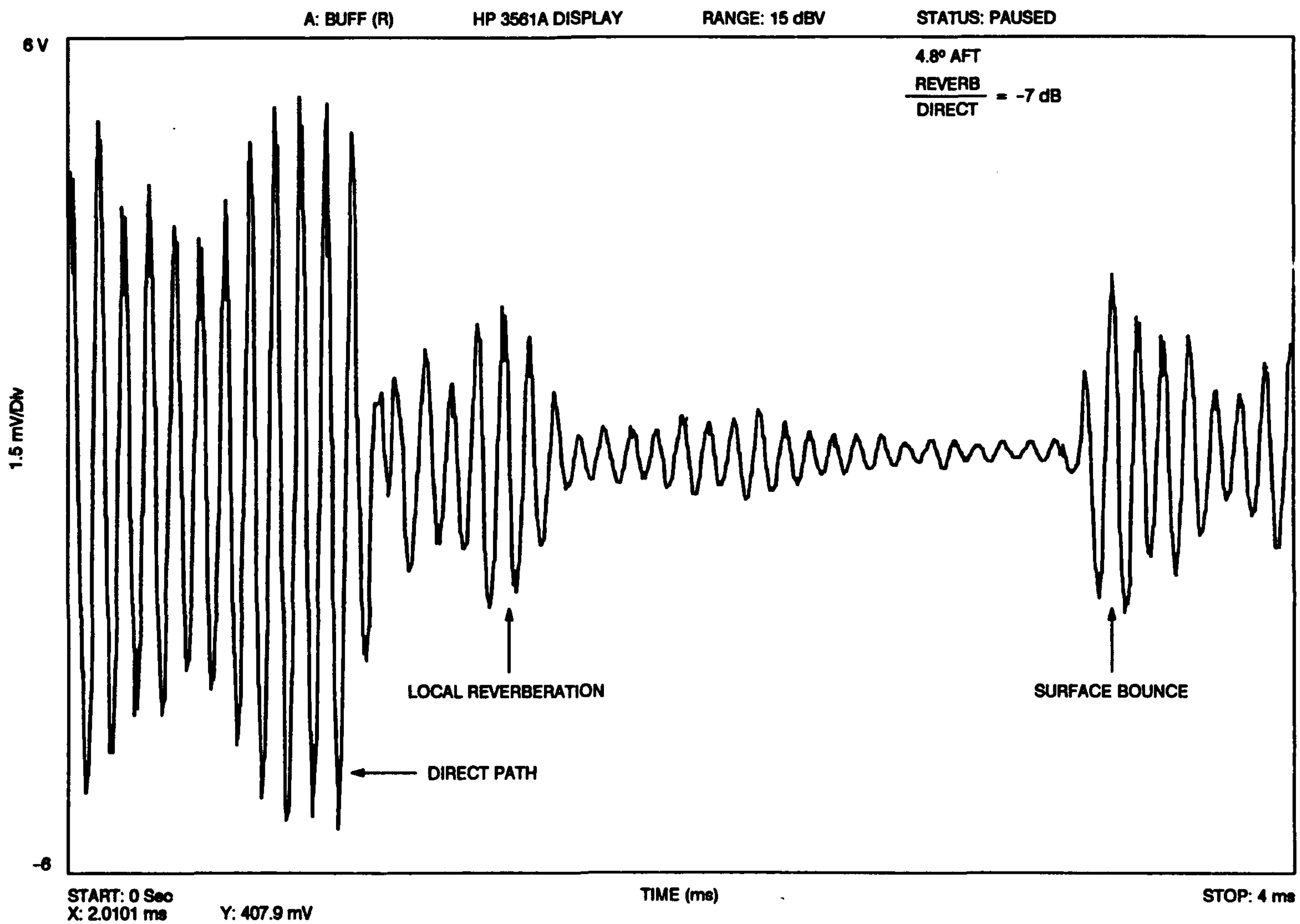

Figure 6. Typical plot with near-surface transducer.

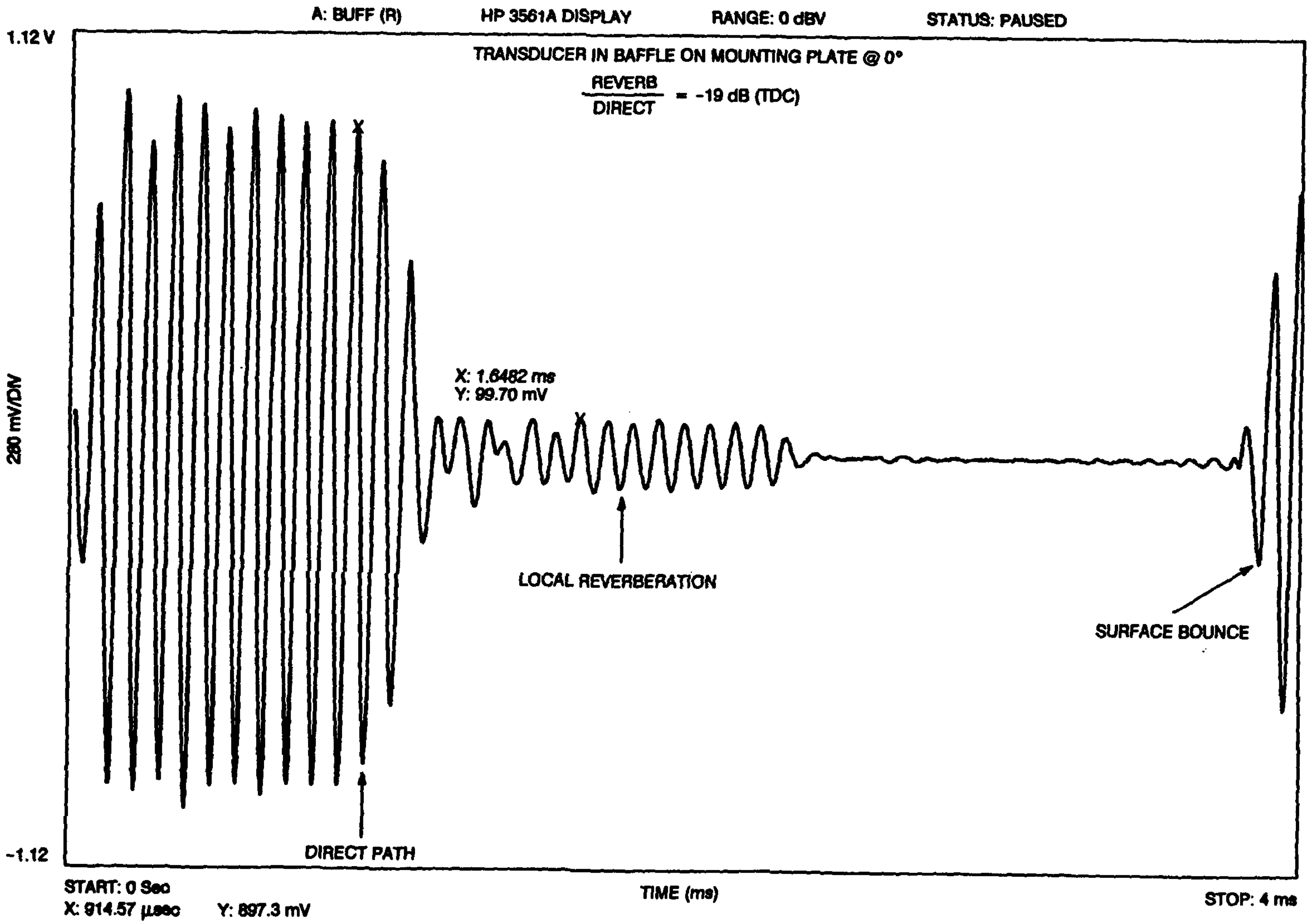

Figure 7. Pole-mounted configuration.

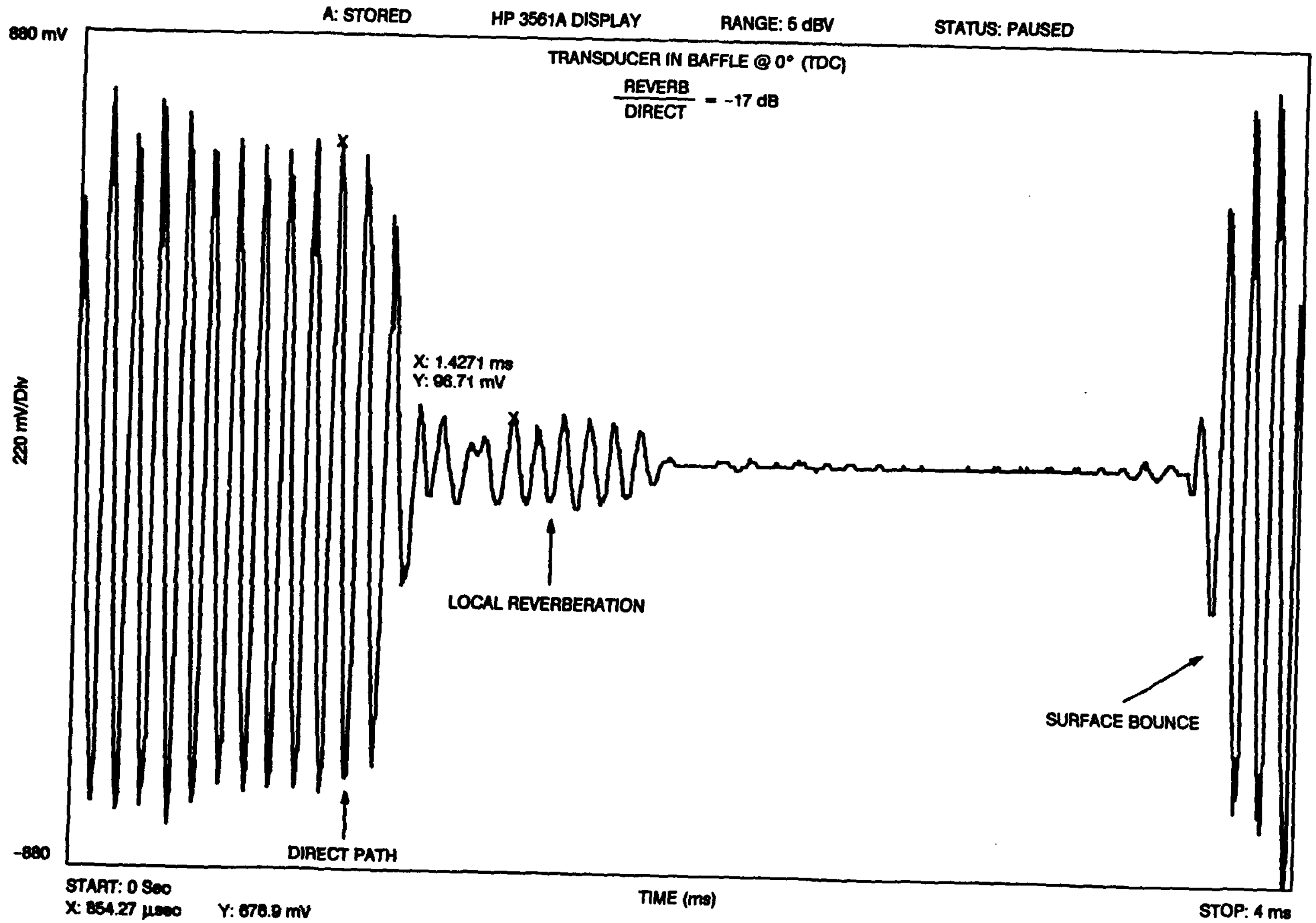

Figure 8. Mounting plate removed from transducer assembly, reducing duration of ringing.

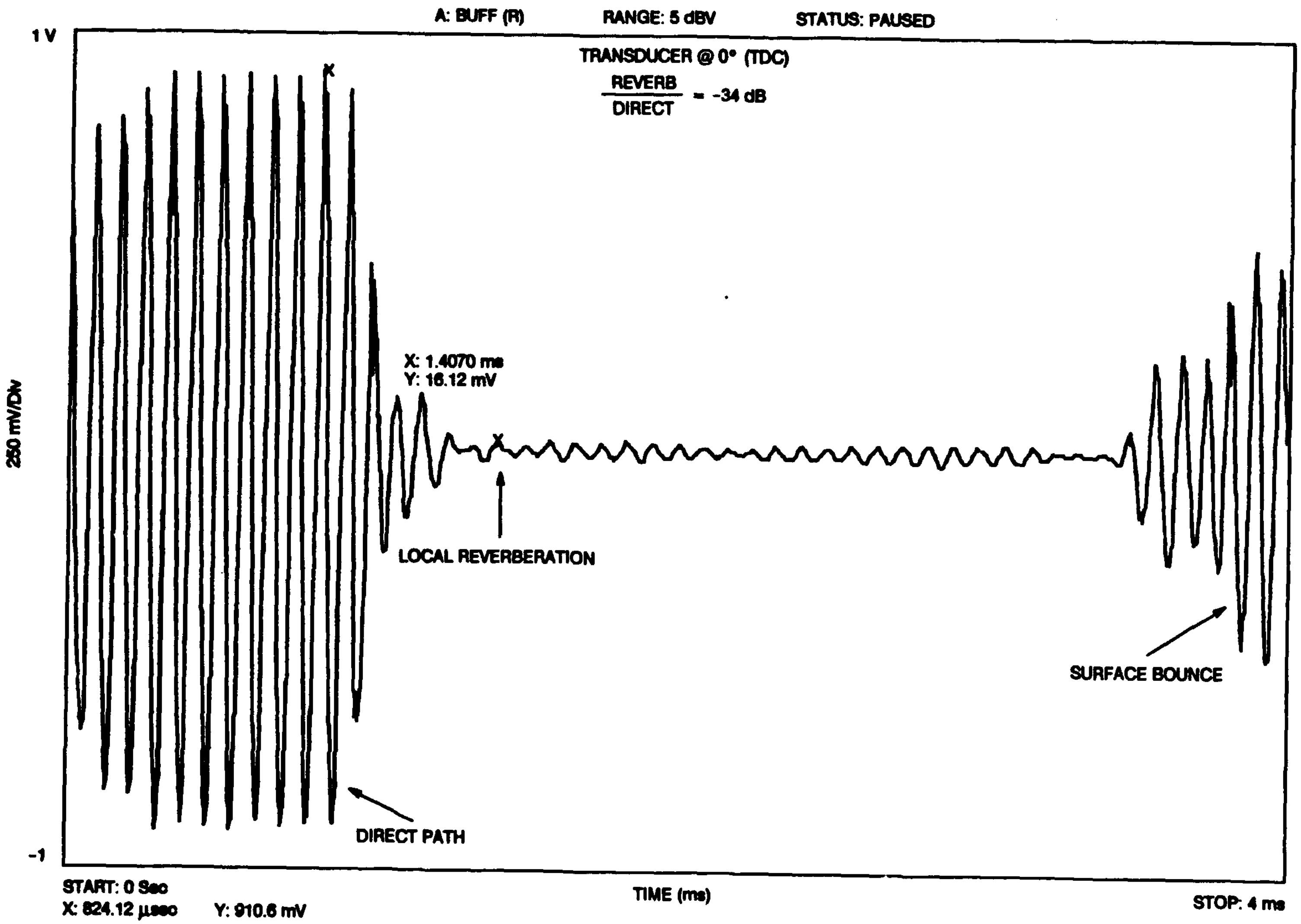

Figure 9. Baffle removed from transducer assembly, nearly eliminating ringing.

Conclusions

A realtime hardware solution to the AL Doppler shift problem was designed, implemented, and proven. This was a tremendous milestone in the development of the AUSS. The bit-error rates of 10^{-3} for 4800-bps transmissions and 10^{-5} for 2400-bps transmissions calculated for the tests done during FY 1987 was a major step toward accomplishing the 10^{-6} bit-error rate measured during the BUMP tests.

Structured FY 1987 sea tests and TRANSDEC tests led to identifying the reverberation problem in the AL transmissions, and to the source of the reverberation. The TRANSDEC tests showed that reverberation problems and their solutions can be identified and tested at the TRANSDEC.

Operation of the AL function through a transducer mounted on the EARS clump during FY 1987 testing showed that the EARS fish was not required for operation of the AL.

Noise levels in the AUSS testbed vehicle affecting the AL system were too high to allow operations at design depth. Efforts to improve this situation with the existing configuration reached the point of diminishing returns. Reduction of this noise could be done by an improved layout of electronic equipment on the vehicle, rewiring, filtering, state-of-the-art power supplies, and an improved propulsion system.

ACOUSTIC TRACKING

Background

A Honeywell RS 906 long baseline system/short baseline system (LBS/SBS) acoustic tracking system was used to track the prototype vehicle and the support ship. The Honeywell outputs were fed to a SEATRAC integrated navigation system for display integration with other on-board tracking systems.

The Honeywell system tracked the vehicle in short baseline, and in long baseline "fish cycle." The position of the ship could be tracked in long baseline. The surface acoustic tracking transducer and short baseline attitude sensors were housed in a vehicle towed behind the ship, the EARS. LBS and SBS tracking of the ship by the Honeywell system occurred at EARS. To assure the stability of the EARS vehicle, it was nearly neutrally buoyant and towed from a heavy clump suspended by a strength member approximately 150 feet below the stern of the ship.

Normally the ship was tracked with the LBS and a Mini-Ranger microwave shore-based system giving an absolute geographic position of the ship. Coordinate systems were determined for the LBS transponder net and the Mini-Ranger tracking that were scaled, rotated, and mapped upon each other.

The position of the AUSS vehicle was determined in the LBS coordinate system by either of two techniques. In the SBS technique, the three-dimensional vector between the vehicle and the ship was determined. The absolute position of the vehicle was computed by adding this vector to the absolute position of the ship.

In the LBS fish-cycle technique, the position of the ship was determined during a first interrogation of the transponder net, and the position of the vehicle (fish) was determined during a second interrogation. The transponder net consisted of four bottom-mounted transponders each of which responded to a 7-kHz interrogation pulse with a different characteristic frequency. During the ship position fix cycle, the 7-kHz interrogation pulse was initiated at the surface ship. During the fish cycle, the 7-kHz interrogation pulse was initiated at the vehicle in response to a 9-kHz interrogation pulse from the ship.

History

The original AUSS concept was based upon a "spot scan" search scenario in which a sonar on board the stationary vehicle would scan an area of the ocean bottom circular in plan view, transmit the data to the surface, and sprint to a new location where another circular spot scan would be conducted. A search area was to be covered by intersecting several of these circles in such a way that no holidays in the coverage existed. A high-tracking accuracy was not required with the spot-scan approach because inaccuracy would be compensated for by overlap. The SBS was chosen for tracking the spot-scan vehicle. The SBS approach would be easy to use since it would not require deployment and surveying of an LBS underwater transponder net.

The AUSS was designed and manufactured based upon the spot-scan search using SBS tracking but was later fitted with a side-looking sonar (SLS) system. Higher search rates are possible with the SLS system, but greater tracking accuracy is desired to support it. The LBS is more accurate than the SBS and was chosen to operate with the SLS search.

The LBS "fish-cycle" tracking was not operational throughout the early stages of AUSS testing. SBS tracking was adequate to keep track of the position of the vehicle during subsystem development and testing. Later testing required accurate tracking for SLS runs, target closures, and target surveys.

Experiments were conducted to determine the nature of the problems associated with operating the LBS fish cycle during the FY 1986 AUSS sea tests. It was found that almost no LBS fixes were possible with the vehicle while transiting. Occasional fixes were possible with the vehicle hovering. Best altitudes were at the transponder net and below. Increasing the width of the 9-kHz fish-cycle initiation pulse appeared to improve the percentage of successful fish-cycles obtained.

A significant long-existing problem within the Honeywell system was identified in FY 1986. A spectrum analyzer was used to analyze the acoustic tracking signals projected from the EARS fish during fish cycle. Instead of projecting a 7-kHz LBS pulse and then delivering a 9-kHz fish-cycle pulse, the Honeywell system was producing 8-kHz pulses. This problem was solved when a faulty component was found and replaced in the Honeywell system.

A combination of system improvements and improved tactics led to an excellent demonstration of fish cycle accuracy in FY 1986. The AUSS vehicle closed (with forward looking sonar) and fixed the position (with LBS on) of five bottom targets during a single dive. The minimum number of LBS fixes taken at each target location was 10. The error radius around the mean value in each of the data sets was 10 feet or less. This was a major accomplishment for a hovering vehicle, but the fish cycle was still not reliable and did not work at all with the vehicle transiting.

Some work was done to improve the SBS accuracy, although it was considered a backup to the LBS. The error circle for the SBS was around 400 feet in the 2500-foot-deep operations area. Analysis of test data uncovered an error due to the rotational misalignment between the compass and the SBS transducer in the EARS fish. There was a significant offset even though the compass and the transducer were accurately aligned mechanically. Data were collected while the ship navigated in a square around the position of the hovering vehicle. The data collected were then subjected to a least squares fit. Range computed by the Honeywell system to the vehicle was honored, but the depression and bearing angles to the vehicle were varied until the error between the computed vehicle fixes was minimized. The determined depression and bearing errors were used to reorient the EARS Honeywell transducer with respect to the EARS compass. The error circle was reduced to approximately 100 feet.

Acoustic Tracking During FY 1987 Sea Tests

More tests were conducted in an effort to identify problems in the performance of the fish cycle in FY 1987. It was found that signal to noise, surface reflection, and beam shadowing all contributed to the LBS fish-cycle problems. Effort was concentrated on the reliability of the fish-cycle tracking while hovering and while transiting.

Recurrent fliers were observed in fish-cycle position fixes. The fixes were offset in a direction away from the position of a particular ocean-bottom-tracking transponder. The fliers occurred more frequently on days when the ocean surface was smooth. An operational solution to this problem involved commanding the Honeywell system to ignore the problem transponder in its fish-cycle solution. Analysis of the Honeywell data revealed that the computed slant range between the suspect transponder and the vehicle was the actual slant range plus a distance in the order of twice the local water depth. This

led to a hypothesis that the surface reflection and not the direct path of the fish-cycle interrogate pulse was activating the transponder. A second hypothesis was that the bottom-mounted transponders were shadowed by the vehicle from the direct path of the interrogation pulse. Also, the vehicle transducer used to interrogate the tracking net was the acoustic link transducer. The acoustic link transducer was baffled to form a hemispherical upward-looking beam.

To test the hypotheses, the vehicle was operated at altitudes below the acoustic transponder net. Further tests were done with the vehicle resting on the ocean bottom. In each case, the reliability of the fish cycle to fix the position of the vehicle improved.

During the next series of tests, the acoustic link transducer was raised well above the vehicle skin. The elevated transducer produced improved fish-cycle performance at altitudes above and below the altitude of the transponder net.

A high-power acoustic link amplifier was developed and tested in preparation for deeper operation of the AUSS vehicle. This provided an opportunity to add another transducer (powered by the amplifier) to the vehicle. An omnidirectional transducer was placed above the video camera in the after vehicle fairing. The acoustic link transducer was used to receive the 9-kHz fish-cycle initiation pulse, and the new transducer was used to interrogate the transponder net. The fish cycle was greatly improved with the separate transducer. For the first time, the fish cycle was reliable as long as the vehicle was not transmitting and not transiting. The performance of the fish cycle was improved for the transiting vehicle. The fish cycle accurately tracked the vehicle around 50 percent of the time during 1.6-knot runs (low speed).

As configured, the separate transducer was not a viable final solution since it was placed above the skin of the vehicle where it would affect the hydrodynamic performance. Also, the transducer could be shadowed from transponders below it by the body of the vehicle. The same omnidirectional transducer was moved to a position on the vehicle centerline aft of the main thrusters. The assembly consisting of the transducer and the extension placing it behind the thrusters was identified as the "stinger." Good fish-cycle performance was obtained with the stinger configuration. In particular, during a 4-knot run, there were no errors in the fish-cycle tracking except when the vehicle was communicating over the acoustic link. To minimize the interference between the acoustic link and the fish cycle, the vehicle status update rate was decreased from once every 15 seconds to once every 60 seconds.

The EARS vehicle provides a stable platform primarily for improved performance of the SBS. Since the preferred prototype acoustic-tracking technique was LBS, a less stable platform may be used. To prove this, a transducer was mounted on the EARS depressor clump. The clump transducer was used successfully to track in LBS for several dives with no degradation in performance.

Conclusions and Recommendations

A test evolution of the AUSS vehicle LBS fish-cycle transducer configurations resulted in the use of a "stinger" transducer located behind the thrusters on the centerline of the vehicle. This configuration is the most favorable hydrodynamically, and provides the best performance of the fish cycle. The stinger approach results in the most reliable fish-cycle operation for hovering and transiting, and is recommended for all future AUSS configurations.

The stinger improves the probability that a bottom transponder will respond to the direct path fish-cycle interrogation. It does not, however, eliminate the possibility that the direct path will fail to activate a transponder, resulting in no response or a response from the surface-reflected path. This is especially true when the transponder is directly ahead of the vehicle and is therefore shadowed from the stinger. To counter this, the acoustic navigation system should be able to recognize and ignore such fliers in its position fix computation, and/or the system should have a range-gate capability on the fish cycle. The Honeywell system used did not have either of these features.

Fish-cycle tracking was not possible when the vehicle acoustic link was transmitting. During sea tests, this problem was dealt with by providing vehicle acoustic link quiet periods during which the fish cycle could operate. The quiet periods were provided manually via commands initiated by the vehicle operator. To improve the performance of both the acoustic link and the fish cycle, prevention of interference between the two subsystems should be handled by the AUSS automatically.

The LBS fish-cycle accuracy was adequate to perform the AUSS mission. Based upon experimental results, the repeatability and relative error of the fish cycle was within a 20-foot-diameter circle in 2500 feet of water. SBS fixes were accurate within an error circle of 100 feet in 2500 feet of water. The error of both LBS and SBS is expected to increase with increasing depth. The LBS accuracy will be affected primarily by the error associated with the increased time between the LBS fix of the ship and the vehicle fish-cycle fix when both platforms continue to move. A desirable feature in the AUSS acoustic navigation system would be a scheme that corrects for the movement of the ship and the vehicle during the time between the ship LBS fix and the vehicle fish-cycle fix. The correction would be based upon the time between the fixes and an estimated relative velocity vector between the ship and the vehicle.

The AUSS vehicle LBS fish-cycle acoustic tracking has been developed into a viable technique for use with an operational AUSS through testing, experimentation, and development.

VEHICLE NAVIGATION

System Description

The vehicle navigation system is a critical element of the AUSS. It enables the vehicle to perform its supervisory-commanded tasks to the required degree of accuracy with minimal operator intervention. The navigation system allows the vehicle to perform such tasks as side-looking sonar search, target closure for classification, and station- keeping with simple commands telemetered acoustically from the surface. Due to the propagation delay inherent in acoustic telemetry, it would be extremely difficult and time-consuming, if not impossible, to perform these tasks without an accurate vehicle navigation system. The vehicle must "know" where it is at all times if it is to perform meaningful tasks. The vehicle is not controlled with a joystick as is done with a conventional remotely operated vehicle (ROV).

A gyrocompass and a Doppler sonar are the main components of the vehicle navigation system. The gyrocompass provides vehicle heading information and the Doppler sonar provides vehicle fore–aft and port–starboard velocity relative to the bottom. This information is used by the main vehicle computer to keep track of the vehicle's position.

An acoustic long baseline tracking system is used by the operators to periodically locate the vehicle accurately relative to an ocean-bottom-anchored-transponder net. This allows the operators to independently monitor the vehicle's position and, when necessary, command a correction via the acoustic link. Without these periodic corrections, the vehicle position error (drift) could grow with time to unacceptable levels.

The vehicle position error is the result of imperfections in the navigation sensors (Doppler sonar and gyrocompass). Due to the limited accuracy and resolution of the gyro, position errors in directions perpendicular to commanded headings accumulate with time. Due to acoustic and processing errors, velocity readings from the Doppler sonar are noisy and subject to occasional dropouts. These shortfalls cause additional position errors, which also can accumulate with time.

The LBS allows the operators to locate the vehicle and command position corrections. However, since this procedure steals time from the search task (data transmission), its use should be kept to a minimum. For example, in deep water, it will take 20 seconds to locate the vehicle using the LBS and additional time to acoustically command an open-loop position correction. This is time during which the vehicle cannot be telemetering data to the surface. Improved vehicle navigation sensors can reduce the frequency of the position updates and hence improve the area search rate of the system.

History

The original gyro used on the vehicle was a Humphrey DG-04-0115-1 flux gate gyro. It was replaced in 1985 with a Robertson subsea gyrocompass. The Robertson, with an accuracy four times that of the Humphrey, has operated reliably ever since. Its synchro outputs have been used exclusively since the RS-232 outputs are not as reliable. When employing the RS-232 outputs, occasional resets or power cycles were required.

The Doppler sonar used on the prototype vehicle was a modified Ametek-Straza MRQ-3016-C originally purchased for the Remote Unmanned Work System (RUWS) project. Modifications performed by Ametek-Straza included a specially designed aluminum soundhead for deep-operating depths, extended receiver blanking after transmission to compensate for soundhead ringing, special circuitry for low-altitude operation, and special circuitry to enable automatic switching of operating mode as a function of altitude. Also, since the sonar was to be mounted in the vehicle, the usual topside display electronics were not provided. Special hardware and software interfaces were designed at NOSC to process the raw-velocity data from the unit.

Unlike the Robertson gyrocompass, the Doppler sonar had a long history of unreliability and performance problems. Many of these problems can likely be attributed to inadequate engineering and/or execution of the aforementioned modifications. Some of the problems, and NOSC's attempted solutions, are detailed in the following.

In the original Doppler sonar system, receiver gains were decreased to compensate for ringing in the soundhead induced by the transmit signal. The blanking modification was apparently inadequate to deal with the problem. The low receiver gains precluded reliable performance at altitudes much greater than 20 feet. To increase the receiver gain without further extending receiver blanking (which would have increased the minimum operating altitude), a time-varied gain circuit was added to each of the four receiver channels. This addition provided each receiver with a gain that increased gradually with time after each transmit pulse. In this way, transducer soundhead ringing was accommodated without sacrificing maximum or minimum operating altitudes.

In an attempt to minimize the amount of bad velocity data output from the sonar, circuitry was added to disable data output whenever any of the four receivers' phase-locked loops indicated that they had lost lock. An indication of when the data output was disabled was also provided to the vehicle computer to enable it to compensate for the resulting loss of data. Additional filtering of the Doppler velocity data was performed in the vehicle computer to discard flyers and smooth the data.

FY 1987 Doppler Performance Tests

Vehicle sea tests during FY 1987 indicated the Doppler sonar data generated when the vehicle was hovering or moving slowly were of little use. Laboratory tests in which

synthesizers were used to feed simulated Doppler-shifted signals into the Doppler electronics verified there was a low-velocity threshold of approximately 0.75 knot below which the Doppler sonar electronics indicated a velocity of 0 knot. Attempts to correct this situation were unsuccessful. A substantial design modification would be necessary to correct this problem assumed to be the result of electrical cross-coupling between the channels. Even if the electrical cross-coupling were totally eliminated, acoustic cross-coupling would still exist, which would set the system's low-velocity threshold. It should be noted that Ametek-Straza typically tests their sonars at 0, 4, 10, 15, and 20 knots, none of which would reveal this low-speed threshold (dropout) phenomenon.

Vehicle sea tests during FY 1987 also showed the Doppler sonar data quality deteriorated badly when vehicle altitudes exceeded 150 feet. To pinpoint this problem, the automatic gain control voltages of each of the four receivers were monitored via the vehicle's flight recorder as the vehicle's altitude was varied. These voltages indicated that all four channels were functional and the gains of all four channels were near their maximum when the data quality began to deteriorate (greater than 150-foot altitude). Any further increases in the gain, to increase altitude, would require that the system's electronic noise be lowered (a significant redesign effort).

Once the reliable operating envelope (less than 150-foot altitude and greater than 0.75-knot speed) for the Doppler sonar was determined, an attempt was made to evaluate its performance within this envelope. During one of the latest prototype dives, two 2000-foot runs at 3 knots and 80-foot altitude were commanded. At the start and finish of each run, the vehicle was commanded to sit on the bottom so that these points could be accurately located via the LBS. The specified accuracy of the sonar (0.2 percent of distance traveled $\pm$ 0.01 nmi/hr) would allow for a 10.7-foot error in such a run. The errors accumulated during the test were 10 feet and 45 feet. This is reasonable performance considering the inaccuracies of the test; i.e., no Doppler measured for speeds less than 0.75 knot during accelerations and decelerations, during times when the vehicle settled to and left the bottom, and for the duration of the run in the direction perpendicular to the run.

Conclusions

The Doppler sonar used on the AUSS testbed vehicle was not acceptable. Its low-speed threshold of 0.75 knot was too high and its maximum operating altitude of 150 feet was too low. Later versions of this sonar (e.g., the MRQ–3017) are basically of the same design and are expected to have the same limitations. The use of Doppler sonars from other suppliers is being investigated. Particular emphasis is being given to low-speed performance, which is critical to station-keeping by the vehicle, and to measurement response speed and accuracy.

Also, consideration was given to closing the long baseline tracking loop on the vehicle. The vehicle could then periodically correct its accumulated positional error by

interrogating and processing the replies from the transponders. This would more than cut in half the time required to correct and enable the vehicle to navigate accurately without operator intervention. Navigation accuracy would be increased due to the reduction of errors from the ship and vehicle motions and sound-velocity variations along the acoustic paths.

VEHICLE CONTROL

AUSS Vehicle Control Description

The AUSS vehicle control system must be able to control the vehicle in three-dimensional space, both while hovering and during transit. The prototype yaw/heading control was accomplished by applying differential thrust on the horizontal thrusters in both hover and transit modes. Pitch was controlled by differential thrust on forward and after vertical thrusters while in the hover mode. Dynamic depth/pitch was controlled by the elevator during transits where the required pitch was the angle of attack required to change or maintain the desired depth. Depth control while in the hover mode was achieved by controlling the thrust on the vertical thrusters. Static pitch trim was controlled by shifting the vehicle's main battery fore and aft to change the vehicle's center of gravity. Navigational control was achieved by issuing commands to the heading- and depth-control loops. Static roll control was achieved manually by placing small weights in the vehicle to correct the roll.

AUSS Vehicle Control System History

The Naval Research Laboratory (NRL) and NOSC developed the first set of AUSS control routines based on the preliminary design of the prototype vehicle. The first control routines became obsolete since many hardware modifications evolved during the construction of the vehicle. The routines where simple Type 0 controllers based on linear control theory. The set of control routines included both hover heading and depth, and transit heading and depth.

The control routines where modified by NOSC to work on the vehicle computer system. At the same time, a simple computer model of the vehicle was started. During the first bay tests, both the control routines and the computer mathematical model where found to be deficient in many ways. Both were revised until they where adequate for operating in the bay while on a tether. The vehicle's first few untethered at-sea operations showed that what worked well in the bay did not necessarily work well at-sea. The routines tended to overshoot and oscillate. Using the information from the first few untethered dives, the control routines and the vehicle mathematical model were revised and Doppler navigation was added.

As testing progressed, it was found that even though the vehicle was stable in the transit heading and depth modes, the vehicle at times had large offsets from the required heading or depth. This was due to the Type 0 control loop's inability to compensate for changes in the vehicle's trim in both yaw and pitch. Also, tests during this time showed the Humphrey Fluxgate gyrocompass was not accurate enough to perform the long side-scan-sonar runs that were added as part of the mission. The Humphrey gyrocompass was replaced with a Robertson gyrocompass.

The hover position and heading control routines that use the Doppler velocity and position information were found to be unstable in most cases and drifted rapidly from the required location. The instability was due to the sample-to-sample noise in the velocity information. It was also determined that the Doppler velocity information dropped out at velocities less than 0.75 knot. This dropout was the major cause for the rapid drift of the vehicle while in hover. In an attempt to stabilize the control loops, a hysteresis zone was established around the required location. The vehicle made no corrections to its position while inside the zone. This achieved only limited success because of the rapid drift of the vehicle out of zone due to velocity noise bursts in the Doppler data. Once outside the zone, the vehicle would try to reposition itself back to the center of the zone. The implementation of the zone had little or no effect on the drift rate of the vehicle from the required location.

The transit heading control routine was the first control routine to be converted to a Type 1. With a Type 1 control loop, the steady state error is zero. The trouble is that Type 1 control loops are more difficult to stabilize. They require rate feedback to stabilize, which in the prototype required a digital differentiation since there were no rate sensors. The use of Laplace transform mathematics was replaced by Z transforms. Z transforms more accurately describe the operation of the digital-control loop as implemented on the computer as long as the computer is restricted to linear operations and a fixed update rate. With the application of the Z transforms and some at-sea tuning of the control equation coefficients for the transit heading Type 1, the control loop was stable with very little or no offset from the commanded heading.

The transit depth was also changed to a Type 1 control routine and converted to the Z transform notation, but stabilizing the loop was not possible. What was found was that the mathematical model of the vehicle did not accurately model the transit depth mode of operation.

FY 1987 Control Loops

It was decided that a better mathematical model for the vehicle be obtained. Two different approaches were devised. The first was to have the vehicle run varying sinusoidal patterns to determine the resonate frequency points of the vehicle plus control

loop. The second was to determine the step response of the vehicle. The vehicle computer was programmed to perform the tests for both transit heading and depth. The test patterns were then run at various speeds, and the data recorded and plotted. In analyzing the data, it was found there was no good single model. The vehicle response depended greatly on the speed through the water.

By using the information that was gained, the vehicle models for both transit heading and depth were modified and some time was spent running the control loops against the models. Matlab (a linear control simulation package for the IBM PC) allowed a variety of forms, for the different control loops, to be tested quickly before running them with the mathematical model and on the vehicle at sea.

The results from running the transit heading control loop against the model agreed fairly accurately with the results that were obtained from the vehicle at sea. The final transit heading control routines for the vehicle were quick, stable, and had zero offset.

The results from running the transit depth control loop against the model differed from the results that were obtained from the vehicle by varying amounts. They ranged from not good too very bad. In fact, there were only a few cases where the vehicle was even stable. This was traced to three basic factors:

1. An increase in the depth transit control loop to an overall Type 2 in depth, with a Type 1 interloop to control the vehicle's pitch while changing depth. Type 2 control loops in general are very difficult to stabilize because of the added phase shift introduced by added integrators needed to form the Type 2 loop itself.

2. Sensor noise: The normal approach to stabilize the control loop is by feeding back the depth, pitch, and pitch rate. But on the prototype, there were no rate sensors and pitch rate had to be generated mathematically by differentiating the pitch information. The depth sensor produced a frequency that was proportional to the depth that was sampled. The pitch sensor was a simple pendulum whose output was sampled by an analog-to-digital (A/D) converter. The pitch information was then differentiated to form the rate feedback for the interpitch loop. When the sensor noise was added to the vehicle model, the results of the simulation were very similar to those obtained from the vehicle during operation at sea. If the control loop gain was reduced to the point where the vehicle model was stable, the vehicle response was too slow for reasonable vehicle operation.

3. The model's response was still found to differ from the true response of the vehicle with the slow Type 2 control routines. The vehicle was still not completely stable and tended to oscillate.

Control Conclusions

The Type 0 hover heading and depth control routines where sufficient. The Type 1 transit heading control loop worked well, but could have been simplified with the use of a yaw-rate sensor. The transit depth control loop needed a more accurate pitch sensor along with a pitch-rate sensor to achieve the required control and stability. The hover and navigation control requires a Doppler with zero or very small velocity dropout. The Doppler sample-to-sample stability and noise should be as good as possible. If this is not attainable, then the Doppler should be interfaced with an inertial navigation package.

OBSTACLE AVOIDANCE

Obstacle-Avoidance Background

The AUSS vehicle mission requires that it operate in relatively close proximity to the bottom without ramming into something. To do so, the vehicle requires an obstacle-avoidance system. The obstacle-avoidance system planned for the prototype vehicle used the forward-looking sonar, the sensor computer, and the main computer. The sensor computer, using the forward-looking sonar, would detect the obstacle and notify the main computer by firing an interrupt. The main computer, upon receiving the interrupt, would stop the vehicle in the shortest distance possible and notify the surface operator that an obstacle was detected and it was waiting for instructions.

FY 1987 Obstacle Avoidance

The main vehicle was programmed to test a series of different obstacle-avoidance maneuvers to determine the best action to take after an obstacle has been detected. The maneuvers were tested from a GO command with an obstacle interrupt coming from the sensor processor to start the obstacle-avoidance maneuver. The results were measured from the acknowledgment of the interrupt.

The different modes of obstacle avoidance that were tested are listed below:

MODE OPERATION

1 100 percent reverse thrust and elevator 0 deg — where/when the interrupt is received 100 percent reverse thrust and 0-deg elevator angle is applied until the velocity is less than 0.1 knot.

2 Thrust = 0 and elevator angle = 10 deg — where/when the interrupt is received the thrust is set to 0 and 10-deg elevator angle is applied until the velocity is less than 0.1 knot.

3 Thrust = 100 percent and elevator angle = 10 deg — where/when the interrupt is received the thrust is set to 100 percent and 10-deg elevator angle for maximum pitch and rate of depth change until the vehicle has gained 300 ft in altitude.

4 Thrust = –100 percent and elevator angle = 10 deg — where/when the interrupt is received, thrust is set to 100 percent reverse and the elevator angle to 10 deg until the vehicle velocity is less than 0.1 knot.

5 180 deg turn — where/when the interrupt is received the vehicle executes a 180-degree turn at maximum rate.

The maneuvers were started with a velocity of approximately 4.6 knots and a depth of 2350 feet running a GO command. The interrupt occurred 1 to 2 minutes into the run. The results are summarized in table 1:

Table 1. AUSS vehicle obstacle-avoidance maneuvers Doppler performance.

MODE	START/ STOP TIME (mm:ss)	START/ STOP DEPTH (ft)	START/ STOP HEADING (deg)	START/ STOP SPEED (kn)	MAX. PITCH REACH (deg)	START/ STOP N/S (ft)	START/ STOP E/W (ft)
	34:02	2350	355	4.6		752	688
1	34:16	2349	353	0	5.6	809	683
	40:51	2346	355	4.5		1532	618
2	42:57	2308	355	<0.1	24.5	1765	553
	47:16	2346	355	4.6		2150	560
3	47:35	2349	353	0	6.6	2232	553
	58:18	2303	180	3.9		1527	557
5	58:56	2303	360	<0.3	5.0	1487	507
4	time from obs. det.	Alt. gained from start		Horizontal distance traveled			
	60 sec	227 ft		185 ft			

Obstacle-Avoidance Conclusions

There was little performance difference between modes 1 and 4. Both stopped the vehicle in a very short distance (57 ft for mode 1 and 55 ft for mode 4). Mode 1 was also the simplest and was therefore the recommended mode.

SEARCH SENSORS

Background

The primary purpose for the AUSS is to provide a deep-ocean search capability. One of the fundamental requirements for such a system is an adequate selection of search sensors. All the prototype search sensors were highly computer controlled. A minimum amount of special-purpose hardware separated the particular sensor processor from the search sensor's detected signals. This approach afforded maximum flexibility for sensor-data processing and indeed was required for the prototype to fulfill its secondary purpose of serving as a testbed for search concepts and techniques. The prototype search sensor suite consisted of a side-looking-sonar (SLS), a forward-looking sonar (FLS), a video camera, and a still camera. All of these sensors were closely coupled to the computer hardware that provided their control and data-processing functions.

The prototype SLS system was a heavily modified EDO Western SLS. It served as the system's primary search sensor with three dedicated computers directly involved in its controlled and processing functions. An *SLS master computer* controlled and processed data from the port and starboard slave computers. Each of these slave computers interfaced directly with the front-end transmit and receive electronics for their respective side-looking channels. The SLS system provided "live" sonar information to the surface during patterned SLS searches. Each side of the SLS could be independently controlled to operate at selected range scales with a variety of pulse widths, sampling resolutions, tuning techniques, and processing algorithms.

The prototype FLS was a heavily modified EDO Western model M–4059 obstacle-avoidance sonar. Its primary purpose was to provide "live" sonar data to the surface to permit the vehicle operator to close in on a sonar target once it had been detected by the SLS. The FLS did, however, provide a lower resolution search capability when used in the absence of the SLS. The FLS consisted of a mechanically scanned sonar transducer and front-end transmit and receive electronics interfaced to the FLS computer. The FLS was directly computer controlled to operate at selected range scales with a variety of pulse widths, sampling resolutions, tuning techniques, and processing algorithms.

The optical portion of the prototype sensor suite consisted of a Subsea CM8 video camera, a Photosea 35-millimeter still camera, and two Photosea M–1500SX strobes. The

video and still cameras were synchronized with the firing of the strobes via specially designed, computer-controlled electronics. The video camera was directly interfaced to a computer-controlled set of frame-grab electronics that digitized and stored the video information obtained during the strobe flash. The frame-grab electronics resided in the vehicle sensor processor that directly controlled all optical sensor functions and provided post-detection processing of the video image. Video images were processed using histogram-based, linear-contrast enhancement algorithms to provide optimum exposure and contrast, and to allow selection of gray-scale and spatial resolutions for images transmitted to the surface and to on-board recording electronics. The primary purpose of the optical system was to provide contact evaluation of targets originally detected on the SLS. The system could, however, be used during patterned photomosaic runs to provide an optical search and documentation capability.

History

The FLS was originally procured from EDO Western as a specially modified model M–4059 "Obstacle-Avoidance Sonar." The modifications performed by EDO provided computer-controlled interfaces to the standard wet-end and surface portions of the system. This was required for interfacing to the prototype computers since the standard units are designed to operate on cabled systems.

Initial NOSC efforts to interface to the EDO electronics identified several enhancements that would be required for the sonar to fully meet the AUSS requirements. The sonar head positioning proved too limited to provide the required control. In addition, the analog processing and digital sampling and conversion were not flexible enough to provide optimum signal-processing capabilities. Finally, the surface display system interface was cumbersome to control and did not provide overlay capability, nor could it support the increased resolution made possible by enhanced front-end processing.

In an effort to remedy the shortcomings in the EDO interfaces, NOSC replaced the EDO surface plan position indicator (PPI) scan converter with computer display cards in the surface console computer, removed the EDO computer interfaces, and designed a custom computer interface to the wet-end electronics. This required the addition of a NOSC-designed FLS computer. In addition, the analog-processing section of the sonar was heavily modified to provide improved pre-amp and detection electronics and a 12-bit analog-to-digital converter.

The NOSC modifications resulted in a significantly enhanced sonar. The system provided improved head-position control and tuning. In addition, since the computer hardware and software was now a NOSC design, more sophisticated processing techniques were available with software under NOSC control.

The original AUSS concept did not include an SLS. Instead the FLS was to serve as the primary search sensor. However, as a result of an early design review and the strong

urging of those in attendance, an SLS was designed and added to the system. The EDO SLS electronics were similar to FLS for which NOSC had already generated custom modifications. As a result, those portions of the EDO system that could be used in a modified design (transducers and front-end electronics) were procured.

The SLS front-end electronics were modified to duplicate the existing electronics for the FLS. To provide a flexible computer interface adequate for the SLS-processing demand, a master-slave computer architecture was developed for the SLS.

During early prototype at-sea testing, a problem was discovered in the sonar images obtained from the FLS. The apparent cause of the problem was the non-normal incidence of the acoustic wavefronts with the sonar window in the nose of the vehicle. The problem was dubbed the "black hole" because it generated a darkened centralized area of diminished sonar return on the surface display. This problem was addressed in FY 1987 by several acoustic window experiments. To analyze the problem it was necessary to obtain unprocessed sonar data obtained at depth. This necessitated an on-board recording capability. A reel-to-reel stereo audio recorder was added to the vehicle to provide an on-board sonar recording function. Custom-designed frequency modulation (FM) electronics were added to permit recording the detected sonar returns on the audio tracks. This recorder was chosen because of its small size and weight and its frequency-response capabilities. The system however had only limited record time, was difficult to control, and provided poor post-dive correlation of signals.

The original AUSS video camera was a SUBSEA CM8 with an ultracon tube. The ultracon tube was selected to provide increased sensitivity. A computer-controlled iris built into the camera lens was to provide exposure control. No usable pictures could be obtained since the iris could not be adequately controlled when used with strobe illumination. As a result, the ultracon tube and the lens/iris assembly were replaced by a standard vidicon tube. This provided usable images but with poor exposure control. Computer software was generated that used the histogram of the digitized image with linear-contrast enhancement algorithms to provide exposure and contrast control. The result was consistently good images, although the lesser sensitivity of this configuration limited the altitude at which images could be obtained.

FY 1987 Accomplishments

Much of the effort expended during FY 1987 was centered on fine-tuning and enhancing existing sensor capabilities. Before FY 1987, all sensors had been interfaced and were operational although not supporting full capabilities.

During FY 1987, a major effort was expended to rid the sonar systems of electrical noise. A major cause of this problem was the close proximity of sensitive sonar electronics to motor controllers and high-current cabling. Trunk lines for power were

separated to isolate the sonar electronics from other portions of the vehicle system. In addition, dc-to-dc converters were added to further isolate the sensitive electronics and to permit more flexible grounding and shielding techniques.

As a result of the noise-quieting efforts, the sonar capabilities were significantly improved. It became possible to detect weaker targets at greater ranges so that the sonars, both FLS and SLS, became viable search sensors.

In addition to the noise-quieting efforts, sonar capabilities were enhanced by the addition of extended variable pulse widths and variable resolution sampling of the sonar returns. Software was added to permit flexible processing and tuning, with a major enhancement provided by incorporating automatic adaptive tuning and processing.

The "black hole" remained a significant problem for the FLS. Extensive effort was expended to understand this problem so that a solution could be found. Sonar signals were recorded and analyzed under a variety of controlled conditions. Numerous parameters were varied including depth of operation, altitude, and tuning both with and without the front nose section of the vehicle in place.

Based on these efforts it became clear that a major cause of the problem was a distortion introduced by the nose section of the vehicle, which also functioned as an acoustic window for the FLS. The angle of incidence of the sonar wavefronts with the material of the acoustic window was non-normal and caused a refraction of both outgoing and returned sonar energy.

A hemispherical dome was fabricated to replace the original vehicle nose section. Initial tests of this dome provided favorable sonar results, although the hydrodynamics of the vehicle were affected. During one dome test, a controlled jettisoning mechanism was added so that the dome could be removed during the dive on command from the surface. This permitted a direct comparison of the sonar data quality both with and without the sonar dome. The results of the FY 1987 testing provided an experimental basis for the redesign of the vehicle nose section.

Another area of FY 1987 emphasis related to the FLS was obstacle avoidance. The FLS transducer beam pattern looks not only forward but also down. As a result, sonar returns from the ocean floor are contained in the returned sonar data. This is required for the sonar to adequately function in FLS mode. However, it significantly complicates the obstacle-avoidance function. Extremely complex software would be required to separate the bottom returns from those returns from potential obstacles ahead of the vehicle.

The most viable approach for obstacle avoidance would be to use a separate transducer for that function. Such a transducer would have a vertically narrow, forward-looking beam pattern whose spreading would not intersect the ocean floor until ranges well beyond the stopping distance of the vehicle. In light of this concept, normalization

and thresholding software for obstacle-avoidance data processing was generated, assuming the existence of such a transducer. A portion of this software was used to simulate the detection of obstacles at sea to test various vehicle obstacle-avoidance maneuvers. The results of those tests are discussed elsewhere in this document.

Because of deficiencies in the already incorporated on-board recording system, in FY 1987 a hi-fi stereo video cassette recorder was used to replace the reel-to-reel recorder. The new recorder extended the amount and quality of data that could be recorded without incurring added weight or power penalties. In addition, video images obtained by the vehicle cameras could be recorded. The video portion of the recorded data was also used to provide a data-logging function so that the operator could monitor critical sensor-related functions, including time marks, to facilitate post dive analysis.

The original sonar interface electronics were modified to permit higher bandwidth simultaneous recording of two channels of sonar information, under computer control. The recorded sonar data were later used to provide a source of raw sonar data for laboratory testing of new sonar-processing functions. These recordings proved quite useful, although it became apparent that a digital-recording technique would be required to provide adequate signal to noise to support many of the most powerful processing functions.

The majority of the FY 1987 optical system efforts were software-based. These efforts provided more control over video camera functions, while speeding up the processing of existing contrast-enhancement algorithms. Capabilities were added to retransmit images to the surface at increased resolution and to enhance the images stored on the vehicle recorder.

During FY 1987, investigations were begun to assess the feasibility of substituting a cooled charge-coupled device (CCD) camera for the vidicon on the vehicle. The CCD camera showed promise for significant improvement to the system. The greater sensitivity of this camera, coupled with its increased signal-to-noise characteristics would provide significant swath and area coverage improvements, since images could be obtained at greater altitudes. In addition, backscatter subtraction techniques showed promise for providing greater image quality even at significant altitudes.

During the latter part of FY 1987, investigations were begun into the feasibility of sensor data compression. Implementation of image compression using the fast cosine transform (FCT) showed great promise. Initial results showed that compression ratios of 10-to-1 or better are achievable. Such compression ratios would make possible significant improvements in area-search rates and also drastic improvements in the quality of sensor images available in realtime to the operator at the surface.

Recommendations

Careful selection of power sources, grounding and shielding techniques, and placement of sensitive electronics are critical for optimum sonar performance. All of these factors need to be carefully considered when designing any vehicle system.

Extreme care is required in the design of the FLS sonar dome. Hydrodynamics and sonar performance are both critical issues in this area.

A separate, narrow-beam transducer is required to implement the obstacle-avoidance function. Design issues related to the incorporation of such a transducer need to be addressed. These issues include hardware interfaces and software processing.

On-board recording of sonar and video data were extremely valuable, not only for testing and evaluation, but also operationally for post-dive detection of targets and for documentation. Such a capability should be retained. To maximize the utility of such a system, the recording function must be implemented digitally. This provides not only the signal-to-noise capabilities required by the sonars, but also the dynamic range and resolution required for improved video-image processing and storage.

A cooled CCD video camera provides significant improvements over the vidicon camera. Improvements in area coverage and image quality made possible by the CCD warrant the effort required for its implementation.

SYSTEM COMPUTERS

Background

The AUSS prototype consisted of a supervisory-controlled, semiautonomous vehicle with surface support systems, all using a highly sophisticated multiple computer architecture. As such, numerous computers were used to perform the many and varied required tasks. Table 2 enumerates the computers and briefly describes their functions and figure 10 shows the interconnecting relationships among the various processors. These computers were divided into three groups: commercial computers, surface computers, and vehicle computers. Within each group several computers operated as loosely coupled-processing nodes, operating in parallel on their assigned tasks.

The commercial computer group consisted of a Honeywell RS–904/906 acoustic-tracking processor and a Seaquest SEATRAC integrated navigation processor. Together, these computers provided an integrated surface and subsurface vehicle-tracking capability. Since these computers are commercially available and do not contain software specifically developed for AUSS, they will not be discussed further.

The surface computer group provided for operator interaction for supervisory command and control input, and also for processing and display of sensor and status

information obtained from the vehicle computers via an acoustic communication link. Computers within this group also supported post-dive analysis of vehicle performance and position parameters. The surface computer group consisted of the surface console computer (SC), the surface acoustic link computer (SA), the overlays computer, and the flight recorder/data-logging computer.

Table 2. AUSS prototype computers.

Name	Function
SURFACE CONSOLE COMPUTER (SC)	Provides primary interface to operator for system command entry, performs received data handling, and display of received STATUS and sensor data.
SURFACE ACOUSTIC LINK COMPUTER (SA)	Controls acoustic link transmit and receive electronics and data formatting and processing to serve as the surface acoustic communication node.
FLIGHT RECORDER/DATA LOGGING COMPUTER	Provides data storage and retrieval for post-dive analysis and plotting of sensor data, position information, and vehicle performance data.
OVERLAYS COMPUTER	Provides a grid overlay and controlled cursor for sonar target marking and range and bearing determination, along with target closure software.
MAIN VEHICLE COMPUTER (MV)	Provides primary vehicle control node for vehicle hotel functions, status monitoring, and command interpretation, propulsion, and navigation.
EMERGENCY PROCESSOR (EP)	Monitors operations of vehicle computers, leak detectors, and power to provide backup for emergency recovery in the event of system failures.

Table 2. AUSS prototype computers. (continued)

Name	Function
VEHICLE ACOUSTIC LINK COMPUTER (VA)	Controls acoustic link transmit and receive electronics and data formatting and processing to serve as the vehicle acoustic communication node.
VEHICLE SENSOR PROCESSOR (VS)	Provides secondary telemetry and communication processing functions and controls search sensor data processing and operations.
FORWARD-LOOKING SONAR COMPUTER (FLS)	Interfaces with forward-looking sonar electronics to provide forward-looking sonar search and obstacle-avoidance functions.
SIDE-LOOKING SONAR MASTER COMPUTER (SLSM)	Controls port and starboard side-looking slave computers to perform side-looking sonar searches.
PORT AND STARBOARD SIDE-LOOKING SONAR SLAVE COMPUTERS (PSLS and (SSLS)	Interface with respective side-looking sonar electronics, under control of the MASTER computer, to conduct side-looking sonar searches.

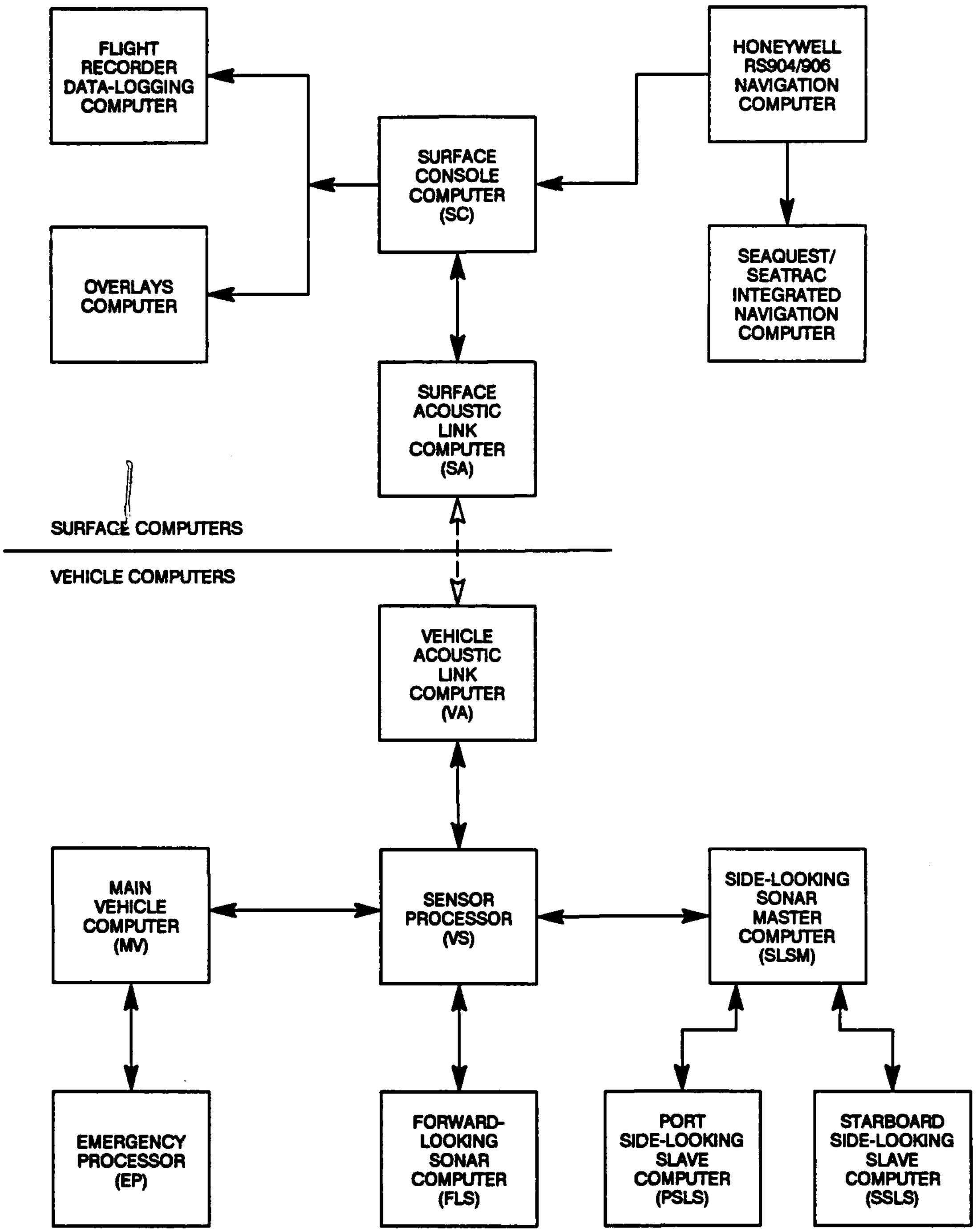

Figure 10. AUSS prototype processors.

The vehicle computers provided vehicle control and status-reporting functions in addition to sensor control and data acquisition and processing. The vehicle computers can be logically partitioned into two groups: the vehicle control group and the sensor processing and communications group. The processors in the vehicle control group were the main vehicle computer (MV) and the emergency processor (EP). The computers in the sensor processing and communications group were the vehicle sensor processor (VS), the vehicle acoustic link computer (VA), the forward-looking sonar computer (FLS), the side-looking sonar master computer (SLSM), and the port and starboard side-looking sonar slave computers (PSLS and SSLS).

To a large extent, each computer in the system operated independently of the other computers on designated, internally contained tasks. Command, control, and data passing between computers were via point-to-point communication channels. The allocation of specific tasks to individual computers within the prototype was based largely upon functional partitioning. This was a fundamental feature of the overall prototype software-development concept. This partitioning permitted isolation of computer interactions to their hardware interfaces. Each of these interfaces adheres to strictly defined, static protocols. As a result, the software development for individual computers could be conducted independently, leading to simplified development and testing.

History

Due to the concept of separable computer tasks, it was possible to develop the initial software for several of the prototype computers as parallel efforts, while suspending development of software for other computers to a later date. As a result, the software development was divided into two phases. The first phase consisted of simultaneous parallel development of software for the primary AUSS computers (the surface console computer, the main vehicle computer, the vehicle sensor processor, and the surface and vehicle acoustic link computers) by separate development teams. These primary computers (and their respective software packages) comprised the minimum set required to form a functional baseline. With the exception of the surface console software, all initial codes were generated by NOSC personnel. The initial surface console software was functionally defined by NOSC and generated under a contract with Systems Explorations, Incorporated (SEI).

The primary thrust of the initial development efforts was to establish a working software/hardware baseline in which each computer was able to communicate over its defined interfaces with other computers and perform the minimum number of functions required for the initial system. Once this baseline had been coded and tested, further capabilities were added on a system-wide prioritized basis. Thus, a working, but simplified system was integrated and tested as soon as possible, and formed the baseline for further development.

Once the baseline system had been augmented by adequate application software and tested on a tether off the NOSC piers, open-ocean testing began in FY 1984. In parallel with these tests, further development of application codes for the primary computers continued. In addition, as time permitted and requirements dictated, software development for the secondary computers (FLS, SLSM, PSLS, and SSLS) was initiated along with the necessary support and control codes in the primary computers.

A working FLS was first tested at sea in February of FY 1986; and the side-looking sonar suite consisting of the master, and port and starboard slave computers was first tested at sea in March of FY 1986. The incorporation of the side-looking sonar suite of computers completed the integration phase for AUSS computers. Thereafter, development efforts concentrated on incorporation and testing of application codes with the goal of attaining a completely operational, full function search system. These efforts culminated in FY 1987 with the performance of a simulated search demonstration (discussed elsewhere in this report).

FY 1987 Computer Systems Accomplishments

The primary FY 1987 software development effort was directed toward increasing efficiencies and enhancing the capabilities of already existing functions. Many of the enhancements were required in order to transition the system from a status of "adequate" testbed to a full-function system. In addition, significant effort was made in the area of full-system testing to assess existing capabilities and areas where substantial improvements could be made. The discussions of FY 1987 accomplishments which follow are divided into four sections. The first section briefly discusses modifications to the software development effort that were incorporated in FY 1987. Thereafter follows a section discussing the surface computer group accomplishments, followed by sections discussing the vehicle control group and sensor processing and communications group accomplishments.

FY 1987 Software Development

A major accomplishment in FY 1987 was incorporating a method for software development and management on PCs. In an effort to gain better control of SC software generated by SEI, the source code from dozens of 8-inch floppy diskettes was transferred to the hard disk of an IBM compatible. The code was then organized into logical directories, and commercially available software for editing, compiling, and linking was implemented. The advantages of this new method were proven when various errors were found and corrected during an attempt to verify the original code. It was possible to speed up and automate compiling and linking by use of disk operating system (DOS) batch files and a "make" utility; and file-archiving and printing were done more easily via networked NOSC central computers.

Based on the success of this approach, software development for the VS vehicle sensor processor was also transferred to a PC-based development host. Furthermore, continual hardware problems surfaced in the old development systems that were still required for programming. A PC-compatible gang programmer was acquired that significantly reduced the time required to implement software changes into firmware.

FY 1987 Surface Computers Accomplishments

As a result of numerous at-sea tests, deficiencies were noted in the operation of the SC. Many of the deficiencies arose from increased capabilities that had been incorporated into the vehicle computers. Since the SC software had been generated by the contractor (SEI), a follow-on contract was written to remedy these deficiencies. In addition, the contract required final software documentation and the training of NOSC personnel so that further software development would not require contracted help.

Modifications to the existing software included: (1) removing scrolling from the side-looking sonar data displays, (2) adding a data-logging port for output of sensor data from the vehicle so that it could be recorded and replayed on a PC for further analysis, (3) eliminating unnecessary navigation input and output ports, (4) adding the capability for optional external synchronization of video displays, and (5) modifying the operator menus for several commands. Two additional efforts of major impact were increasing the efficiency of uplink-data handling and adding the sensor processor utility (SPU) command. The modification of uplink-data handling required a major restructuring of the manner in which message units within the application code interacted with the RMX86 operating system. This restructuring improved reliability and considerably improved console-response time even under increasing processor loading. The addition of the SPU command involved the addition of the equivalent of 27 different command menus. The SPU command provided the operator with a "user friendly" interface, which significantly increased his control of vehicle sensor operations and laid the groundwork for numerous enhancements in sensor-data handling.

Extensive modifications were made to the software of the flight recorder/data-logging computer. These modifications significantly increased the efficiency of the post–dive analysis while making the operator interactions more "user friendly." To accomplish this, the navigation-plotting software for the flight recorder/data-logging PC was rewritten. The new version was screen-oriented, with paper output optional. Automatic scaling was performed, and photomosaic-area coverage was shown by small rectangles. Plots could be rescaled or recentered and rapidly redrawn.

During sonar searches, and especially for vehicle closure on targets, a need existed to obtain range and bearing to targets on the sonar displays. As a result, in FY 1987, a third PC, the overlays computer was incorporated into the surface computer group. This

computer-generated text and graphics were merged with the pixel display output of the SC to form an annotated grid overlay. The computer monitored the Uplink American Standard Code for Information Interchange (ASCII) data, and automatically updates the overlay annotation for the appropriate overlay grid, for the port, starboard, or FLS. The operator was able to position a cursor over targets on the sonar display, to mark those targets. The computer then calculated range and bearing information to the marked targets. A target-closure algorithm calculated current drift from the apparent motion of the target between successive scans, and calculated recommended vehicle location and heading for upstream approach. The overlays computer could also log data to disk, and thus free the flight recorder/data-logging computer for other tasks during the dive.

FY 1987 Vehicle Control Group Accomplishments

In FY 1987, numerous changes and enhancements were made to the software for the control group of processors; these are summarized below.

The GAIN command interpretation was changed to allow the reconfiguration of the vehicle control system from the surface, and therefore, to experiment with and refine the control-loop coefficients and configurations. The new SPU command was added to the commands the vehicle could receive. The status report task was updated by removing many of the unused temperature parameters and replacing them with distance to the target, horizontal and vertical thruster command values, and acoustic-noise-measurement data.

The Doppler interface task was modified by adding a software switch to allow the selection of the type of data (raw or processed) that was to be stored in the flight recorder. This permitted the acquisition of Doppler-performance data correlated with other vehicle parameters. These data were used to modify the computer mathematical model so that it would better reflect the actual vehicle performance. The updated mathematical model was used not only for analysis purposes, but also formed a predictor as a portion of the vehicle control system. The SLS search operations were modified so that unneeded sonar transmissions, which disrupted Honeywell fish-cycle navigation, could be disabled during a turn. The method by which the altitude and depth command registers were updated was modified to correct problems that had occurred during mode shifts between depth and altitude holds. Software interface drivers, in both the EP and the MV, were rewritten to introduce a resynchronization capability, and to improve the reliability of this interface.

The main battery monitor and power control software were modified, to permit a quick controlled-power-down sequence, in the event of a battery malfunction. Hardware-interrupt and interrupt-handler tasks for obstacle avoidance were added, along with the ability to switch between various obstacle-avoidance maneuvers.

FY 1987 Sensor Processing and Communications Group Accomplishments

The following modifications were made to the sensor processing and communications group.

A "warm boot" function was added to the sensor processor so that, in the event of a reset, the system configuration and critical data could be retained. Sonar functions for controlled blanking, variable pulse width and variable resolution sampling, were incorporated, along with various tuning methods including an adaptive automatic tuning technique. On-board video recorder functions were added to annotate the recorded video information with status information and time. Video processing functions were added to speed up the linear contrast-enhancement software, to enhance images recorded on the on-board VCR, to control camera offset and gain, and to permit retransmission of images under higher resolution. Acoustic communication reliability was enhanced by the addition of adaptive noise tolerance software. This software provided improved checking of data validity, template matching to be used in the event of partially corrupted receptions, and synthesis of valid data blocks from multiple transmissions of corrupted data.

Recommendations

The AUSS prototype experienced computer reliability problems, caused mainly by circuit card edge connectors and interconnect cabling. The number of interconnecting cables should be significantly reduced by combining computer assets onto shared backplanes. The number of conductors for the remaining cables should be reduced by replacing the parallel communications interfaces with a serial, party-line architecture.

The prototype computers exhibited unequal software-processing loads, and were configured in a suboptimum architecture. This was largely a result of the initial testbed nature of the system. Extensive at-sea system testing led to some functional redefinition. As a result, some of the computers reached the limit of their processing capabilities, while others remained underutilized.

Initial analysis showed that, with the proper ohoice of new computer hardware, and with some reconfiguration of the system computer architecture, all system deficiencies could be overcome. In light of past experience and the state of detailed knowledge about system requirements, it was possible to repartition the computer functions so that the processing loads could be equalized. This permits more modular and efficient software, which is easier to document and maintain.

AUSS PROTOTYPE SEARCH DEMONSTRATION TESTING

INTRODUCTION

A search demonstration was conducted at the close of the Advanced Unmanned Search System (AUSS) FY 1987 sea testing. The demonstration was performed late in the FY 1987 effort to benefit from earlier system improvements and risk-reduction efforts.

TERMINOLOGY

Several terms associated with AUSS search demonstration and testing and used in this document are explained below:

Acoustic shadowing — a beam of an acoustic device is interrupted by a solid object.

Acoustic tracking system — a system that uses underwater acoustics to determine the relative positions of equipment in the water. Distances are determined by the time taken for sound to travel from one position to another.

Acoustic transponder — a device which responds to sound, at one frequency, by transmitting at another frequency.

Bit-error rate — measure of accuracy in transmission of digital data, usually determined by the number of incorrect bits received divided by the total number of bits transmitted.

Broad-area search — rapid search of the ocean bottom using a low-resolution sensor. Classification (identification) of contacts perceived with broad-area-search sensors is not usually possible. A typical broad-area-search sensor is the SLS.

Contact — a search sensor image perceived by the search system operator as an item of interest on the bottom of the ocean. Contacts may be real or "false" (i.e., not what is being sought).

Contact evaluation — close scrutiny of a contact to determine if it is a target of interest and, if it is, what are its characteristics. This normally involves the use of high-resolution sensors at close range to the contact.

Doppler sonar — an acoustic sensor used to determine the velocity and position of a vehicle with respect to the bottom of the ocean.

Fish-cycle acoustic tracking — a long baseline acoustic-tracking technique used to determine (fix) the position of a "fish" (i.e., the AUSS vehicle).

Forward-looking sonar (FLS) — an acoustic sensor used to scan the area forward of an underwater vehicle. For AUSS, the FLS has a mechanically scanned sonar

"head" which transmits and receives a beam very similar to the beam of the SLS. A sonagram is developed representing the area in front of the vehicle as the head is mechanically scanned back and forth across the bow.

Immediate contact evaluation — stopping during a broad area search to perform a contact evaluation.

Long baseline acoustic tracking — a technique by which the position of equipment in the water is determined in three dimensions. This is done by determining the distance from the equipment to at least three bottom-moored transponders (a transponder net) whose positions are known.

Search-area rate — rate at which a search system is able to search the ocean bottom, usually expressed nmi^2/hr.

Side-looking sonar (SLS) — an acoustic search sensor used for searching from an underwater vehicle advancing in a straight line at a constant velocity. Successive pings (perpendicular to the track of the vehicle) are sent out from the sonar that are narrow-beamed along the track of the vehicle, but are wide-beamed in the vertical. The times of return of these pings are used to determine the position on the bottom from which the sound was reflected.

Sonagram — a visual representation of information collected by a sonar.

Supervisory control — control technique in which the human operator supervises the operation of a remote system. The operator communicates with the remote system infrequently. In between these communications, the remote system performs a series of preprogrammed functions selected by the operator. When finished with a series of preprogrammed functions, the vehicle awaits further instructions.

Target — a real contact.

OBJECTIVES

1. Conduct a representative search demonstration with the prototype AUSS.
2. Operate prototype AUSS as a supervisory-controlled search system.
3. Use AUSS immediate contact evaluation tactics.
4. Quantify AUSS prototype search demonstration using search times.
5. Evaluate AUSS prototype performance and define deficiencies.

TEST AREA

The FY 1987 prototype search demonstration was conducted in the AUSS operations area (OPAREA) used for all previous AUSS dives. The area had a flat sandy silt bottom,

and was near the center of OPAREA 37-03 shown in figure 11. The water was nominally 2,500-feet deep and this AUSS OPAREA was approximately one statute mile on a side. Slightly inside the four corners of this OPAREA were four long baseline system (LBS) acoustic-tracking transponders with floats suspending them approximately 100 feet above the sea floor. Six automobiles and three groups of three engine blocks were laid down on the ocean bottom, all of which were used as sonar and optical targets. The locations of the transponders, the automobiles, and engine blocks are pictorially shown in figure 12.

VEHICLE CONFIGURATION

The AUSS prototype testbed vehicle could not be optimized to simultaneously perform all the functions necessary in a search. Modifications to the "standard" AUSS testbed vehicle configuration to enhance the performance of subsystems was done at the expense of poor performance elsewhere. The AUSS testbed vehicle was configured for good performance of the acoustic link at 4800 bps, and for good performance of the fish-cycle tracking during the search demonstration.

The acoustic-link transducer and baffle were elevated above the body of the vehicle for good acoustic-link performance. The elevated transducer avoided acoustic shadowing previously experienced. A separate fish-cycle transducer was added to the tail end of the vehicle on its centerline and extended beyond the thrusters. The separate omnidirectional fish-cycle transducer communicated more reliably with the transponder net than when the fish-cycle function was performed by the acoustic-link hemispherical beam transducer. Vehicle hydrodynamics were compromised by the placement of these transducers.

The placement of the additional transducer on the tail end of the vehicle also presented a weight and balance problem. The moment and increased weight were compensated for by removing the still photograph camera from the vehicle and adding counter-balance weights in the appropriate locations. (The photographic capability of the vehicle was proven during previous dives.)

SETUP

After launch and descent, the AUSS vehicle was commanded to transit to a position in the northwest quadrant of the OPAREA. At this point, the vehicle was given commands via the acoustic link that set up an autonomous search pattern using Doppler sonar/compass navigation and SLS search. The search track was composed of three parallel legs: (1) the first leg from west to east for 3000 feet, an interleg turn; (2) a 3000-foot east-to-west search leg, an interleg turn; (3) and a final 3000-foot west-to-east search leg. The port and starboard SLS were set to scan on the 400-meter-range scale. The parallel legs were to be spaced such that there would be 150 percent coverage of the OPAREA (the 800-meter swath searched during the second parallel leg would overlay the first and third by 400-meters each, and would thus be covered twice).

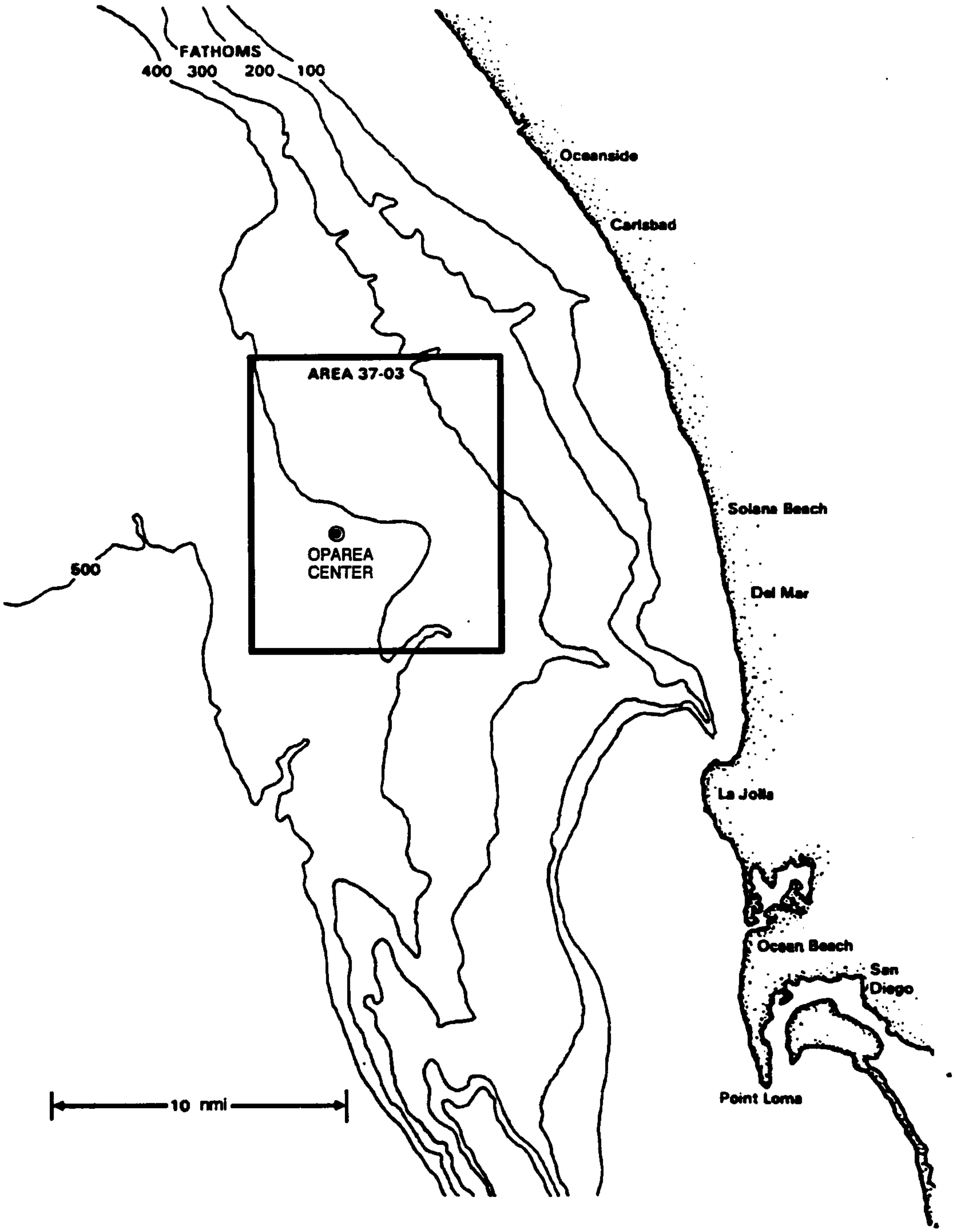

Figure 11. AUSS operations area.

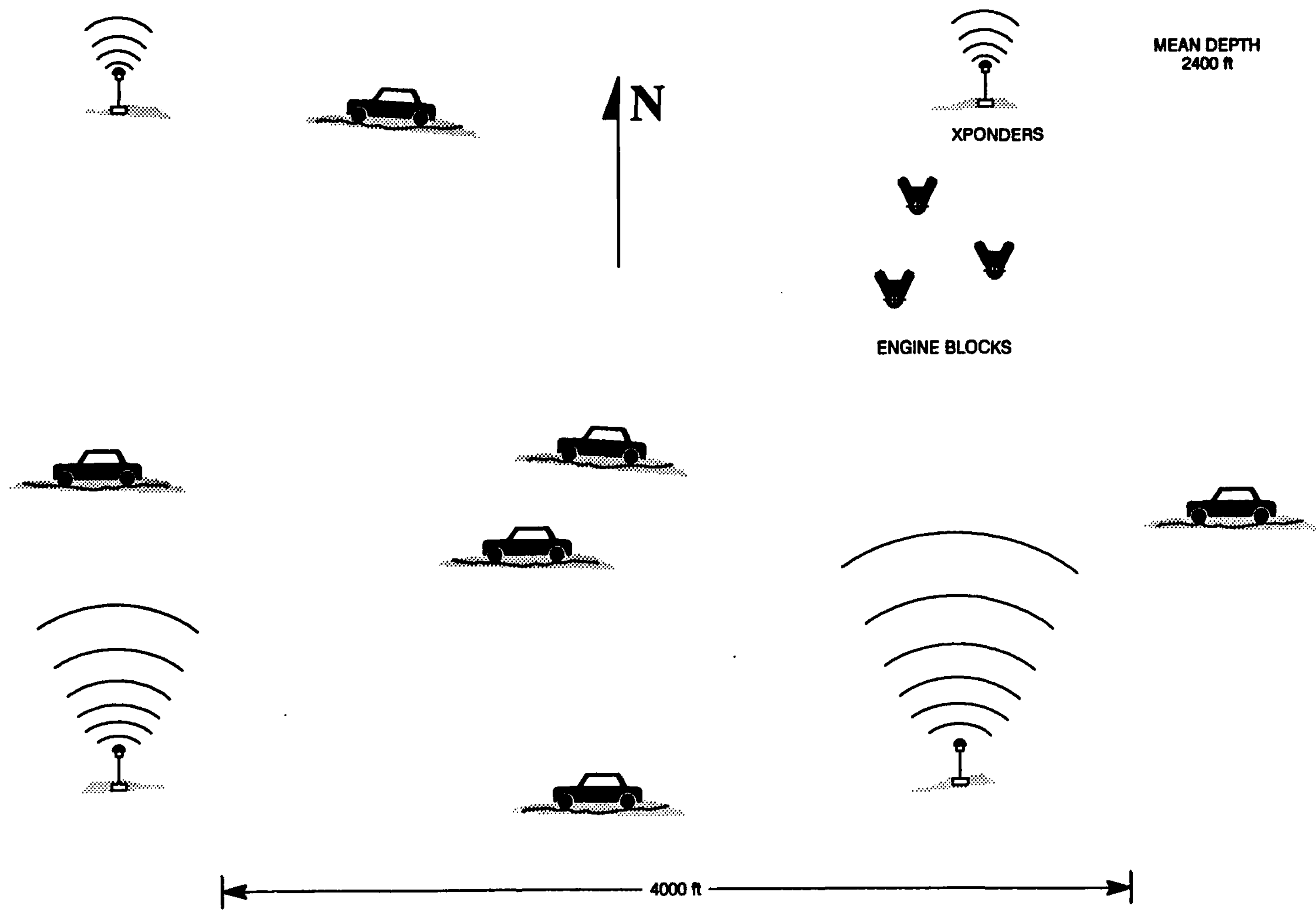

Figure 12. AUSS test site.

Software to allow near-continuous transmission of the SLS data to the surface was not fully implemented for the demonstration. For this reason, the speed of the vehicle was limited to 1.6 knots to avoid along-track holidays (gaps) in the SLS data transmitted to the surface. The vehicle altitude was limited to 80 feet to assure continued performance of the Doppler sonar. Turns were run at speeds above 0.75 knot and no navigation stops were planned to avoid drop-out in the Doppler sonar navigation (a phenomenon that occurs at low speeds). Acoustic navigation fixes were to be made during the turns, when the SLS was not transmitting.

Transmission of all vehicle data to the surface was at 4800 bps, and all commands were sent to the vehicle at 1200 bps.

GENERAL APPROACH

A general approach is given here to the conduct of the demonstration including running search legs and performing contact evaluations.

The broad area search was conducted with the SLS on west-to-east or east-to-west search legs. All SLS contacts were immediately evaluated. When an SLS contact was made, the vehicle was immediately commanded to stop and an acoustic navigation fix was taken. The vehicle was next commanded to turn and scan perpendicular to the SLS track with its FLS. When necessary, the contact was closed in further and another FLS scan taken. Once a target was detected with the FLS, the vehicle was allowed to drift, but holding the same heading. After a few minutes of drifting, a second scan was made. The water current vector was determined by using range and bearing information from the two FLS scans.

The AUSS vehicle was next commanded to transit to a point down-current from the target position and turn into the current. The vehicle was then commanded to slowly "close in" on the target (transmitting sequential FLS sonagrams to the operator while slowly thrusting forward) until the target was in view of the video camera. After assuring video documentation, acoustic navigation fixes were taken of the vehicle to pinpoint the target location.

A computer program called "X1Y1X2Y2" was used to compute a vector from the target position to the position at which the vehicle departed from its search track. The AUSS vehicle was commanded to transit back to the search track along the computed vector.

THE SEARCH

A representation of the actual track run by the AUSS vehicle during the demonstration is shown in figure 13. Points tagged by capital letters are positioned on the plot using

acoustic navigation fixes of AUSS obtained with AUSS LBS fish-cycle tracking. Tracks run between the lettered points were plotted based upon AUSS Doppler sonar navigation data. The Doppler sonar navigation data were stored in the AUSS vehicle on-board flight recorder, and retrieved through the acoustic link after the demonstration was completed. The retrieved Doppler sonar data were stored on a disk in the AUSS Compaq computer. Figure 14 is a plot of the coordinates generated by the Doppler sonar and stored in the flight recorder. Differences between figures 13 and 14 will be discussed later in this report.

The search started at point A of figure 13. During the first leg, a target was detected on the port SLS. The contact evaluation of target #1 went as described in the preceding section, General Approach, except that incorrect use of the freshly written program "X1Y1X2Y2" led to a reverse course to point D instead of back to the search track. The procedure was corrected and the vehicle was returned to point E to continue on leg 1 of the search track. The vehicle did not autonomously continue on its search track at this point since the initial track had been interrupted. The track from E to F was a single-leg search track and the transit from F to G was a dead-reckoning track initiated by the vehicle operator through the acoustic link.

After a short dead-reckoning correction (needed due to Doppler sonar navigation error resulting in overshoot at point G) the vehicle ran autonomously down search leg 2 and turned to pass through point H. Point H was obtained from the fish-cycle acoustic tracking while AUSS was advancing through the water (on the fly). Fish-cycle fixes are not normally possible on the fly because of tracking system interference generated by propulsion and the SLS. No targets were detected during the east-to-west portion of this path, although there were definitely targets within SLS range. The subject of detection and nondetection of targets is addressed later in this report.

The first part of leg 3 of the search path was a continuation of the path initiated near point G. Target #2 was detected on the port SLS. The target was out of the FLS range so it was closed using a "blind" dead reckon until it was within FLS range. Target #2 was closed to get video confirmation, and when the AUSS was returned to point K, another single-leg search was initiated.

Target #3 was detected on the starboard SLS. The initial transit from point N put the AUSS close to target #3 and the procedure to determine the current vector was not used. For final closing, the target was approached from an initial direction other than into the current, which severely affected the amount of time it took to close it. In addition, target #3 was closed twice to get good video coverage. The times involved in accomplishing the various target contact evaluations are in the Search Statistics section of this report.

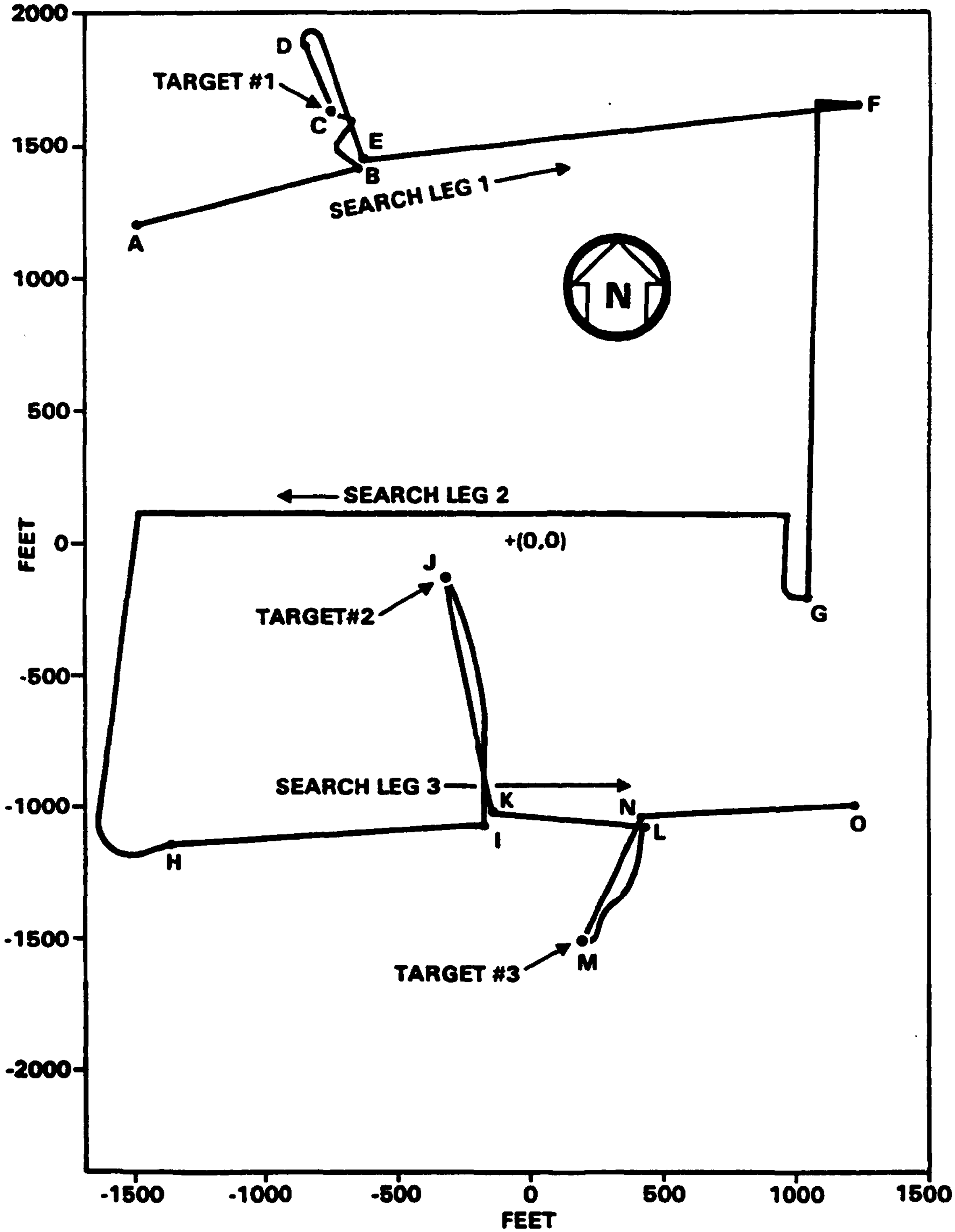

Figure 13. AUSS search demonstration vehicle track.

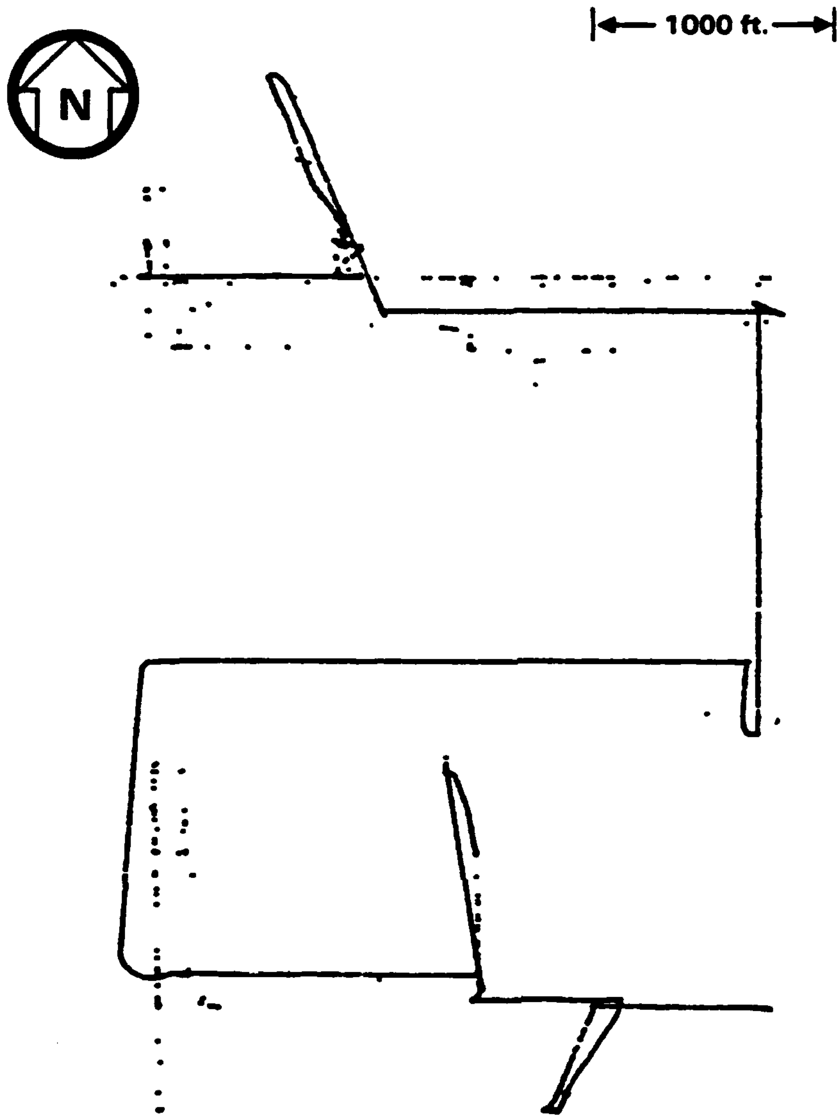

Figure 14. AUSS search demonstration plot of coordinates generated by a vehicle Doppler sonar.

NAVIGATION PERFORMANCE RESULTS

Acoustic fish-cycle tracking of the AUSS vehicle provided good navigation fixes, and is the basis of the track reconstruction in figure 13. Except for one case (see point H in figure 13) fish-cycle fixes were not obtained on the fly. Software changes had been implemented prior to the demonstration that should have allowed the SLS to cease operation during turns and possibly allow fixes on the fly, but a software "glitch" precluded this. To obtain reliable fish-cycle fixes, the vehicle was stopped, the period between acoustic-link-status transmission bursts was increased, and all search activity was ceased.

The Doppler navigation system on the testbed vehicle was inadequate for viable hovering and long-term search maneuvers. To accomplish this demonstration, several "tricks" were employed to produce a reasonable navigation result.

The Doppler sonar would "drop out" at velocities below 0.75 knot, so the search scenario was set up to keep the vehicle advancing at the highest speeds compatible with SLS and acoustic-link performance. Navigation stops within end of leg turns (which are planned as part of a normal AUSS search pattern) were eliminated by a software change to keep the vehicle moving around the turns. Any water current transverse to the track of the vehicle caused a translation normally at a rate less than 0.75 knot, which was therefore not detected by the Doppler navigation system. This effect was minimized by choosing east–west search legs roughly parallel to the current direction at the onset of the search demonstration.

Another error that was independent of the effects of dropout and water current was a drift error in the Doppler/compass navigation system. The absolute magnitude of the drift error increases as a function of time. This effect was minimized by running short search legs, and taking absolute position fixes with the acoustic-tracking system whenever the vehicle was not advancing. Essentially, this demonstration was conducted using the Doppler/compass navigation system as a dead reckoner to navigate between points determined accurately using the acoustic-tracking system.

The ability to hover over a target during optical documentation is required for contact evaluation. The AUSS vehicle was not hovered during this demonstration, but was slowly driven over the target position while optical documentation was obtained on the fly. Acoustic-tracking-position fixes were obtained next, with the vehicle drifting "near" the target position. It was not possible to hover the AUSS testbed vehicle due to the 0.75-knot dropout in the Doppler sonar and general noise in its output.

Figure 13 is a representation of the actual track run by the AUSS vehicle as determined by the acoustic-tracking fixes. Figure 14 is a plot of the points stored in the vehicle flight recorder acquired from the Doppler navigation system. The successive

points plotted in figure 14 are subject to accumulative errors due to system drift, and translations not measured by the Doppler due to water current and velocities below 0.75 knot. A comparison of figures 13 and 14 shows the effect of these cumulative errors. If the path AB is observed in figure 13 and compared to the same path in figure 14, it is seen that the Doppler system controlled the vehicle on what it sensed to be a good west to east course. In reality, between the fixes A and B, it is seen (from figure 13) that the vehicle traveled a significant distance to the north. Between the points B and E, the vehicle was operated at very slow speeds and was subjected to water current translations not measured by the Doppler system. The vehicle operator was able to fairly accurately navigate the vehicle with Doppler/compass dead reckoning from point D to point E near point B, but observation of figure 14 shows a large accumulated error in the Doppler position coordinates between where the vehicle left the search leg and returned to it. Further comparisons of figures 13 and 14 yield similar information on the inadequacy of the Doppler navigation system on the testbed vehicle.

SEARCH STATISTICS

A log was kept of the time each event in the demonstration occurred so that it is possible to determine the time required to perform the various search phases.

Table 3 is a summary of some search demonstration statistics. This search was conducted very conservatively in that 50 percent of the search area was covered twice. This conservatism was necessary because of uncertainty in the performance of the navigation system prior to the demonstration. About 31 *percent* of the demonstration time was lost due to failures and miscellany. This 31 percent loss would be reduced significantly with improved AUSS equipment and more time spent operating the AUSS vehicle in actual search scenarios. With no search path overlap and no failures and miscellany, the search-area rate in table 3 would be 0.19 nmi^2/hr.

Table 4 focuses on target contact evaluation statistics. Targets were detected and closed on both sides of the search track at various distances. There was a significant amount of time lost due to equipment failures and tactical errors as seen in notes 2, 3, and 4. The corrected times (after eliminating failures and tactical errors) for overall contact evaluation are 33, 35, and 29 minutes. The average corrected time for contact evaluation is 32 minutes.

Table 3. AUSS search and demonstration results summary.

AREA COVERED =	0.33 nmi^2
TOTAL TIME =	3 hrs 45 min
TARGETS EVALUATED =	3
RAW AREA-SEARCH RATE =	0.089 nmi^2/hr
RAW AVERAGE TIME PER CONTACT =	47 min
AREA COVERED TWICE =	50 %
BREAKDOWN:	
ON-TRACK SEARCH	53 min
CONNECTING TRACKS	21 min
ACTIVE CONTACT CLOSURE	70 min
RETURNS TO TRACK	11 min
FAILURES	33 min
MISC.	37 min
	3 hr 45 min

TARGET DETECTIONS

All targets detected and evaluated during this demonstration were automobiles previously deployed. Operators of the AUSS vehicle ignored previous knowledge of the positions of targets in the OPAREA during the demonstration. Table 4 shows there were targets detected on both sides of the search path at three different ranges (75 meters, 300 meters, and 150 meters).

Using target #2 as an example, a representation of the series of images transmitted to the operator from the vehicle is shown in figures 15 through 18. During the SLS search, the vehicle advanced at a speed computed by the vehicle to avoid holidays in the along-track sonagram. Successive sonar scans to the port- and starboard-side of the vehicle were processed and transmitted to the surface via the acoustic link. Figure 15 is the sonagram presented to the operator for the port SLS in which target #2 was detected. Starting from the bottom of the screen, horizontal video scans originating from the far right of the screen were stacked upon previous scans as the vehicle advanced. The intensities of the pixels in this sonagram were related to the intensities of the sonar returns from ranges starting at 0 at the right of the screen to 400 meters at the left of the screen. The region of minimal return at the right of the screen represented the water column between the vehicle and the bottom directly below the vehicle. Target #2 was detected and identified on the sonagram by several high-intensity pixels in close proximity at a range of approximately 300 meters.

Table 4. AUSS search demonstration target contact evaluation statistics.

TARGET #	RANGE FROM SLS TRACK (meters)	CONTACT EVALUATION TIME (minutes) (note 1)
1	75 to port	62 (note 2)
2	300 to port	40 (note 3)
3	150 to stbd	40 (note 4)

Notes:

1. Included in contact evaluation are:

   a. Stop vehicle

   b. Fix vehicle position on SLS track with acoustic-tracking system

   c. Reacquire contact on forward-looking sonar (FLS)

   d. Determine current vector using FLS sonagrams of contact while vehicle drifts

   e. Calculate position down-current of contact from which to start final closing

   f. Close in on target and obtain video "snapshot" image

   g. Obtain acoustic-tracking fix of vehicle while over the contact (to mark the contact location).

   h. Calculate a vector for the vehicle to travel back to the position at which the SLS search track was broken

   i. Close back to search track

   j. Obtain navigation fix on vehicle to confirm it is back on the search track

   k. Reinitiate search on remainder of track

2. This time includes 29 minutes lost due to a computer malfunction and operator error. The corrected time would be 33 min.

3. Five minutes were lost reinitiating navigation transponders that had timed out (this reinitiation procedure is required every 5 hours during operations). The corrected time would be 35 min.

4. First video image of the contact was obtained 28 minutes after the SLS detected it. Of the contact evaluation total time, 11 minutes were expended reacquiring the contact for a better video image. Corrected time would be 29 min.

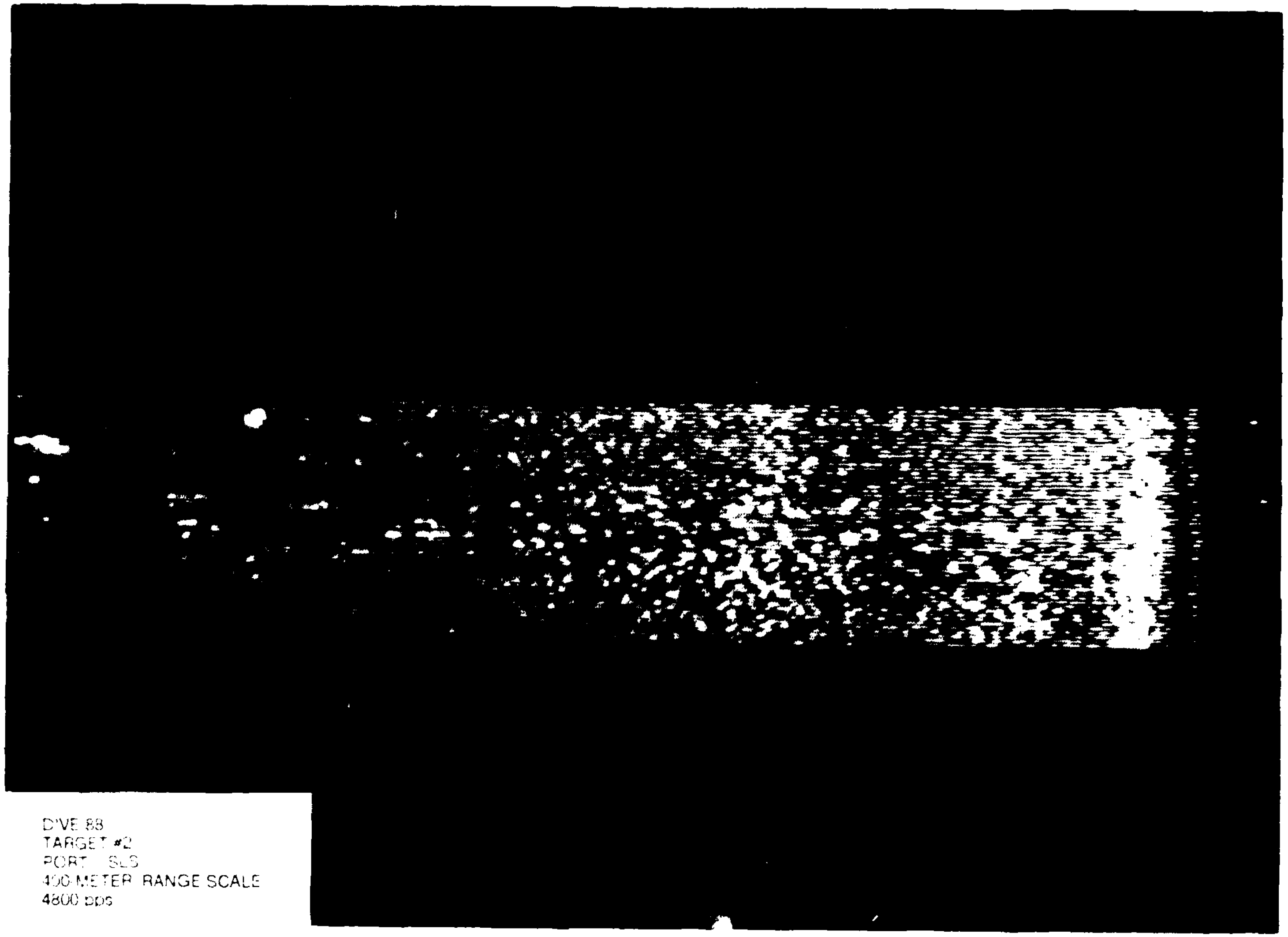

Figure 15. Sonagram for the port SLS, target #2.

After maneuvering the vehicle into a position down–current from the target, the vehicle operator used the FLS to scan the target as the vehicle advanced toward it. Figure 16 is one of many FLS sonagrams obtained while closing in on target #2. The intensities of the pixels in this FLS sonagram were related to the intensity of the sonar returns from ranges starting at 0 on the left to 25 meters on the right-hand side of the screen. The vertical scale of the FLS sonagram was the sonar head angle with respect to the vehicle. The horizontal video scan at the vertical center of the screen represents the scan from directly ahead of the vehicle. Video lines above and below represent port- and starboard-side of the target respectively.

The operator commanded a picture to be taken when the vehicle was over the target. The command initiated a strobe that illuminated the bottom below the vehicle as a frame was "grabbed" from the video camera viewing the bottom. Figure 17 is the low-resolution, 4-bit video image of target #2 transmitted to the operator. After the operator was satisfied the low-resolution image represented a target of interest, he retransmitted the image with higher resolution (for a more detailed look) as was done for target #2 and shown in figure 18.

The video frame grabbed from the video camera could also be recorded on the vehicle on-board VCR as was done for target #2 and shown in figure 19. The image on the VCR was uncorrupted by the processing and transmission associated with the acoustic link, but was retrievable only after the dive is completed. Although the 35-mm camera was not installed during the demonstration dive, a still photo of target #2 obtained during a previous dive was included as figure 20 for comparison with the video images.

Evident from figures 12 and 13, targets were missed during leg 2 of the demonstration. Reconstruction of the search path and previous information on the location of these automobile targets indicated that they were missed at 40 meters to starboard and at 70 meters to port. These targets were missed due to sonagram display hardware failures and poor acoustic telemetry. A post–dive sonagram was extracted from the vehicle VCR audio track and is presented in figure 21. This sonagram shows that a return suggesting a target was processed by the port SLS system along leg 2 of the search. The target is displayed as a cluster of illuminated pixels near the sonagram upper right- hand corner. No starboard sonagram is available for leg 2 of the search since only one SLS output at a time could be recorded on the vehicle.

CONCLUSIONS AND RECOMMENDATIONS

The testbed AUSS was successfully used to perform supervisory-controlled search with an untethered vehicle during this one-dive search demonstration. There were several tactical errors and failures of equipment that affected the results of the testing, but much was learned.

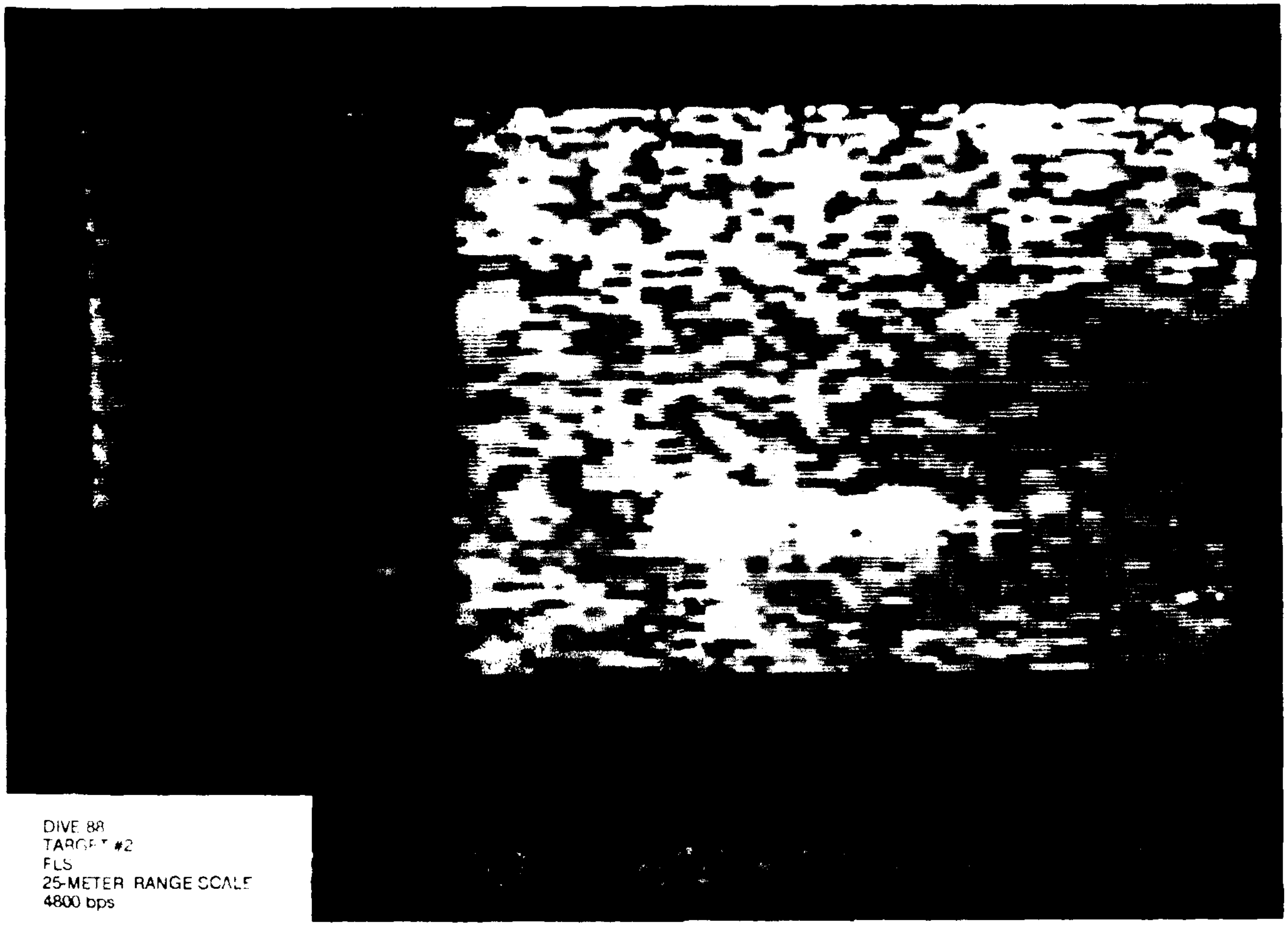

Figure 16. FLS sonagram, target #2, 25-meter-range scale.

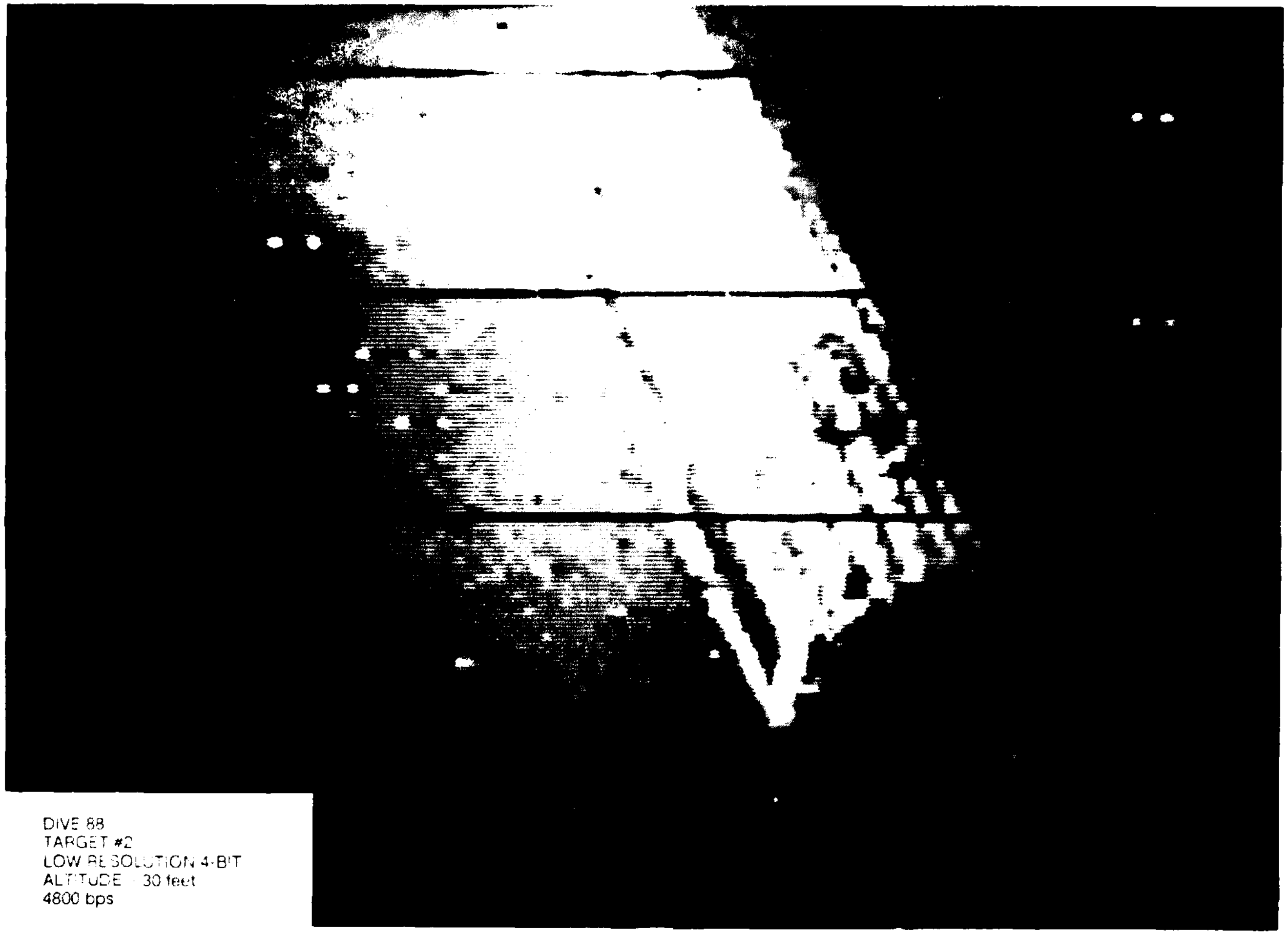

Figure 17. Low-resolution, 4-bit video image of target #2.

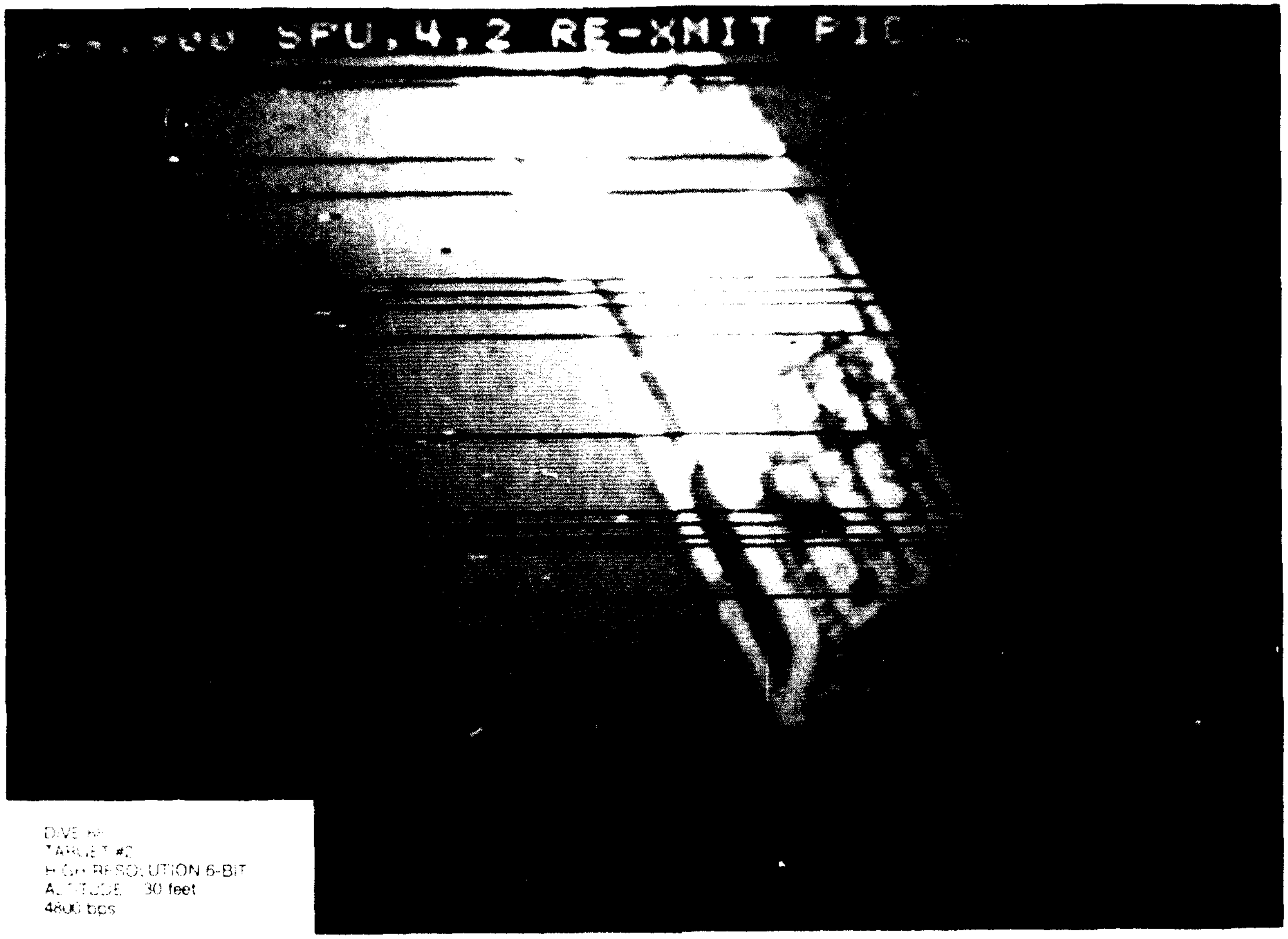

Figure 18. High-resolution, 6-bit video image of target #2.

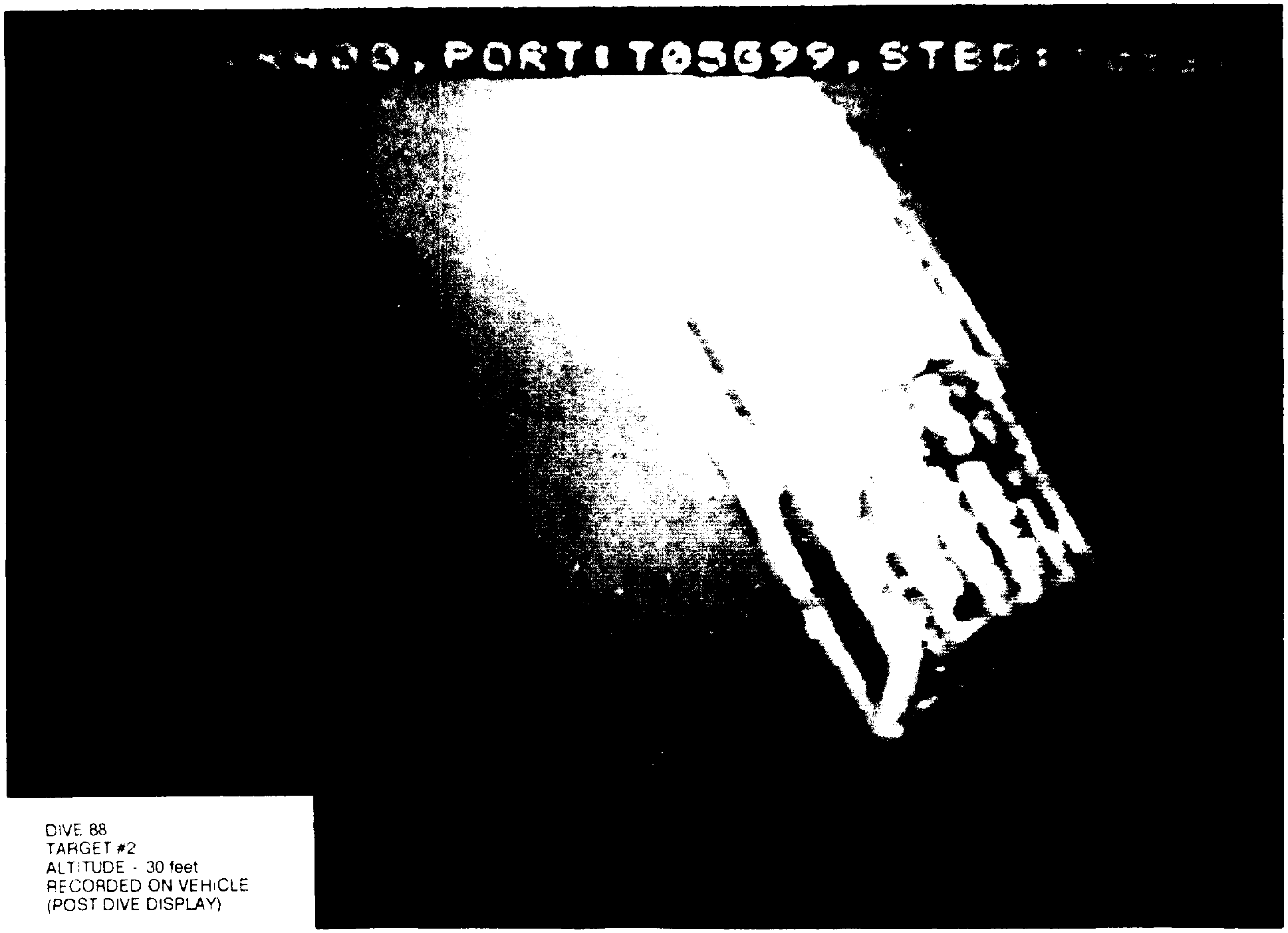

Figure 19. Video image, altitude 30 feet of target #2.

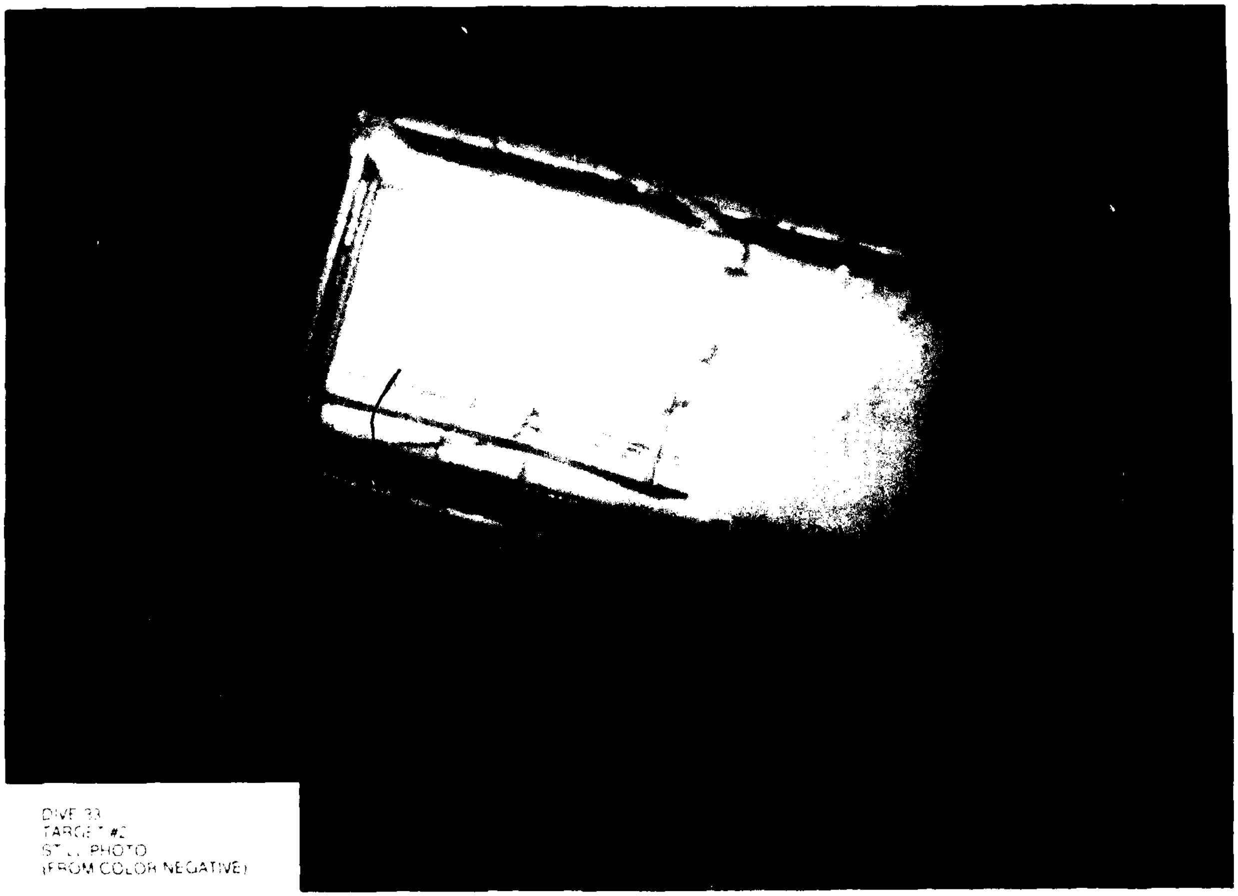

Figure 20. Still photograph of target #2.

Figure 21. Post-dive sonagram by the port SLS, leg 2.

Using improved sensors, more reliable equipment, and less conservative search tactics, search area rates of 0.2 nmi^2/hr and better are obtainable for a flat featureless bottom with low false-target density.

Immediate contact evaluation was used with impressive results. Contact evaluation times (time between SLS detection of a contact and return to search track after evaluating the target) will be within 1/2 hour on a regular basis in the future, based on demonstration results. This will be enhanced by the capability to vector to and hover over the target position during video and acoustic-tracking documentation.

Target images were clearly presented to the operator as long as the system was operating properly. Data compression and image enhancement of sensor information sent to the operator is required. Transmission of compressed and enhanced image information will decrease the burden on the acoustic-link system, and improve the images presented to the operator. The overall result of these efforts will lead to higher area-search rates than was demonstrated.

GLOSSARY

A/D	analog-to-digital (converter)
AL	acoustic link
ASCII	American Standard Code For Information Interchange
AT	acoustic tracking
AUSS	Advanced Unmanned Search System
bps	bits per second
BUMP	benthic untethered multipurpose platform
CB/CG	center of buoyancy – center of gravity
CCD	charge-coupled device
dB	decibel
dc	direct current
D/A	digital-to-analog (converter)
deg	degrees
DOS	disk operating system
EARS	external acoustic relay system
EDO	short for EDO Western, an electronic company
EP	emergency processor
E/W	east-west (runs)
FCT	fast cosine transform
FIFO	first in, first out
FLS	forward-looking sonar
FM	frequency modulated (modulation)
FY	fiscal year
ft	feet
hifi	high fidelity

hr	hour
Hz	hertz
kHz	kilohertz
kn	knots
LBS	long baseline system
Matlab	a linear simulation package for the IBM-PC
min	minute
mm	millimeter
ms	millisecond
MSC	military sealift command
mv	millivolt
MV	main vehicle computer
nmi	nautical mile
NAVSEA	Naval Sea Systems Command
NCCOSC	Naval Command, Control and Ocean Surveillance Center
NOSC	Naval Ocean Systems Center
NRaD	NCCOSC Research, Development, Test, and Evaluation Division
NRL	Naval Research Laboratory
N/S	north-south (runs)
OAS	obstacle-avoidance sonar
OPAREA	operations area
OPS	operations
PC	personal computer
PPI	plan position indicator
PSLS	port side-looking sonar slave computer
RDT&E	research, development, test, and evaluation

ROV	remotely operated vehicle
RUWS	remote unmanned work system
SA	surface acoustic link computer
SBS	short baseline system
SC	surface console computer
SEATRAC	an integrated navigation system
sec	seconds
SLS	side-looking sonar
SLSM	side-looking sonar master computer
SNR	signal-to-noise ratio
SSLS	starboard side-looking sonar slave computer
TRANSDEC	transducer evaluation center
UPS	uninterruptable power supply
VA	vehicle acoustic link computer
VCR	video cassette recorder
VS	vehicle sensor processor
SEI	Systems Explorations, Inc.
SPU	sensor processor utility

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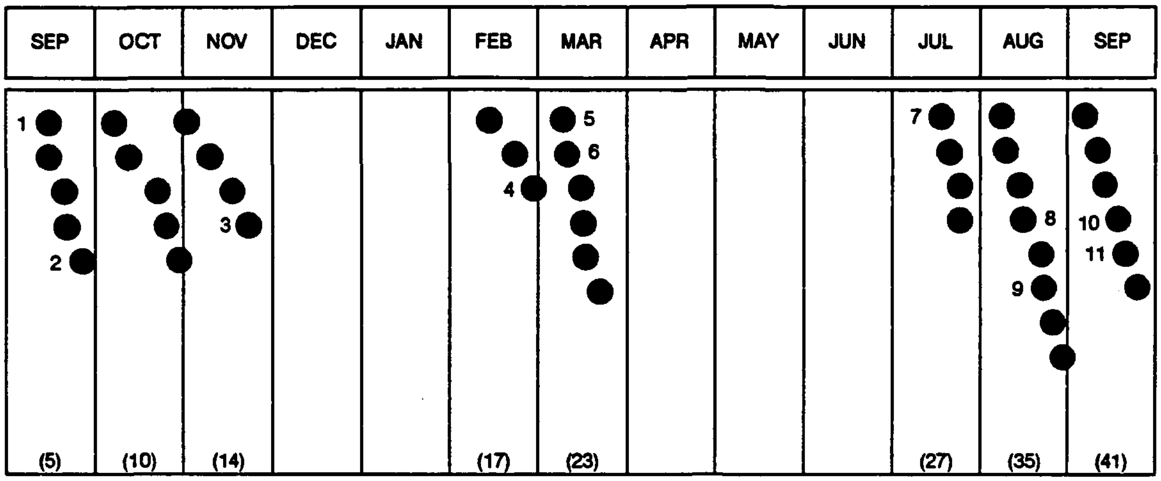
APPENDIX A

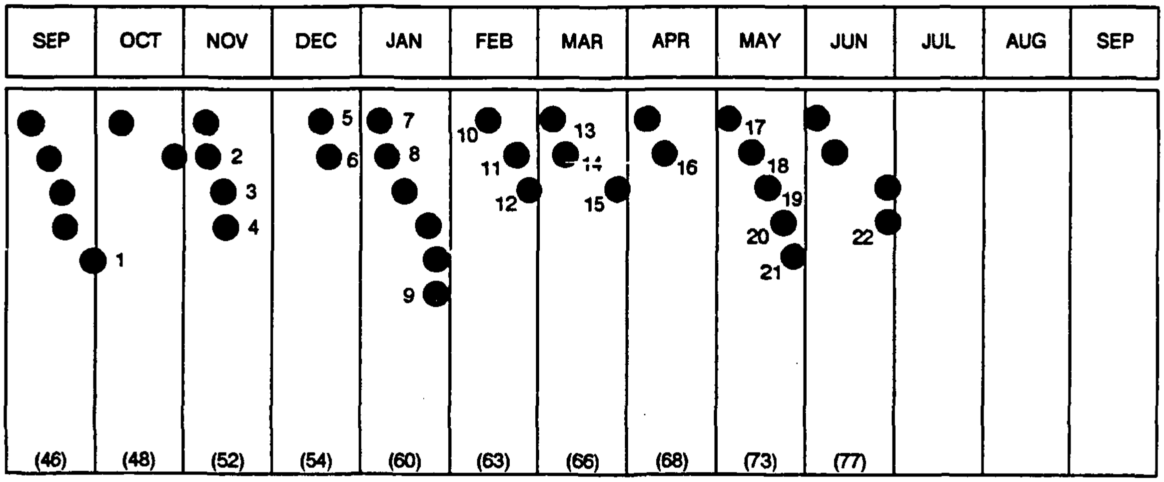
AUSS DIVE HISTORY—FY 1985



1. First dive 12 Sep 84
2. Flight recorder on line
3 First TV transmission (acoustic)
4. Obtained first 35-mm photos
5. First use of silver-zinc battery
6. First free dive
7. New CB-CG, first OAS ops
8. Located car on OAS
9. Good high-data rate pictures
10. Doppler hover and mosaics
11. Tested OAS in SLS mode

APPENDIX B

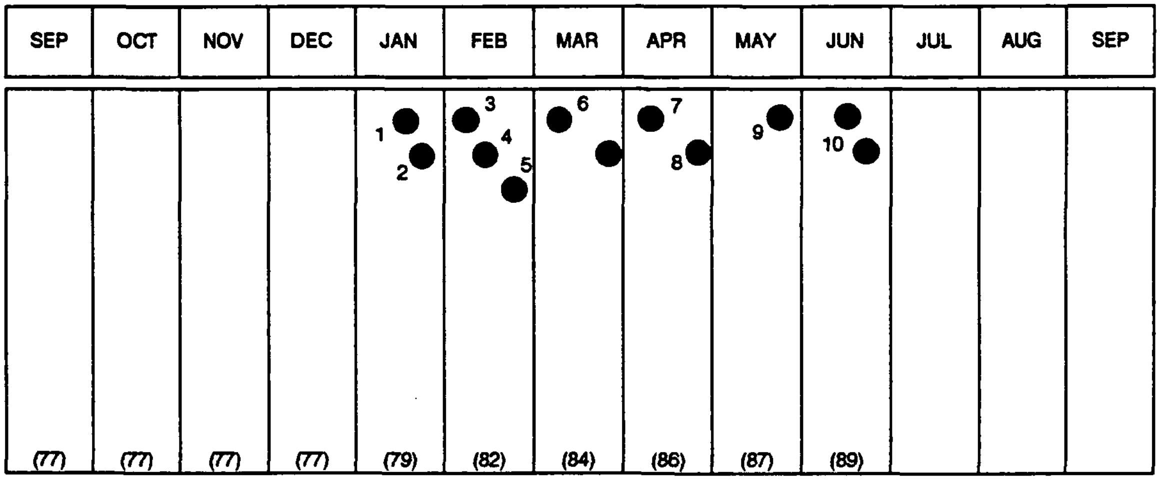
AUSS DIVE HISTORY—FY 1986



1. Type 1 control and GO commands
2. TV of car at 70 ft altitude
3 OAS as "SLS", new targets seen
4. Two-mile transit
5. Refocused TV, photos of desk
6. Surveyed benthos net, more targets
7. First SLS (port only), sea state 3
8. Power down, noisy acoustics, low cell
9. SLS data, two display modes
10. Acoustic link check, good video, large doppler drift, noisy starboard SLS
11. FLS calibrations
12. Cause of FLS Black Hole identified
13. On-board video recording tested
14. Photomosaic run
15. Acoustic-link SNR improvement
16. New EARS cable test
17. Navigation accuracy test
18. Step function control loop test
19. Phase 3 sonar targets verified
20. All Phase 3 navigation and sonar targets deployed
21. All Phase 3 targets surveyed-in
22. SLS target detected at 800 m

APPENDIX C

AUSS DIVE HISTORY—FY 1987



1. First dive from *JAMIE G.*
2. Improved fish cycle, elevated transducer
3 Improved AL signal, elevated transducer
4. Sensor processor utility commands added
5. Poor signal is electric not mechanical. New BST AgZn batteries installed. Established AL problem is Doppler shift potential EARS elimination verified
6. Simulated obstacle avoidance detection and maneuvers
7. Vertical thrust profile data
8. Non-realtime AL Doppler shift corrected. Adaptive noise-tolerant software proven
9. Realtime AL Doppler shift correctio accomplished. Good "fish cycle" per form with separate amplifier/transducer
10. Demonstration dives

APPENDIX D

SAMPLE AUSS DAILY TEST PLAN AND REPORT

DIVE NUMBER(S) 88

DATE: 7-16-87
TEST IDENTIFICATION: Search Scenario Demonstrations
LOCATION: Encinitas 37-03
WEATHER: Calm, Overcast, Dark Rain Clouds on Horizon
DATA LOGGED BY: Jim Walton

PERSONNEL	PRIMARY	BACKUP
TEST DIRECTOR:	J. Walton	
NAVIGATOR:	M. Rutkowski/J. Walton	
VEHICLE OPERATOR:	S. Watson/H. McCracken	
ACOUSTIC LINK:	J. Mackelburg	
DATA LOG:	M. Rutkowski/J. Mackelburg	
OTHER:		

STATED OBJECTIVES

1. Conduct search scenario demonstration including SLS 400-meter-range scale, auto-tuned, square-wave search pattern; target detections; target closures; immediate contact evaluations; and video and acoustic position documentation of the target.

2. Experiment with "realtime" Doppler shift correction equipment. Look for other sources of transmission errors in the acoustic-link system.

3. Test performance of fish-cycle tracking with separate transducer and separate amplifier.

4. Recover current meter.

ACCOMPLISHED/PROBLEMS SINCE LAST DIVE

1. Low-battery cell (#35) investigated and found defective. Cell replaced with new cell. During charge of battery pack, jumpered out cells came up to voltage quickly to allow rest of pack to even out charge better.

2. Repaired radio transmitter that had leaked during last dive.

3. Repaired surface VCR.

4. Installed scrambler in acoustic-link uplink channel transmitter and a descrambler in the receiver. This is the same technique used in BUMP to accomplish random information. It was hoped that the scrambler technique would improve the transmission quality by avoiding patterns.

DIVE EVENTS/OBSERVATIONS

1. Vehicle configuration. Original FLS cover in place. AL transducer elevated. Separate fish-cycle omnididirectional transducer and amplifier installed.

2. Honeywell #4 transponder would not reply during repeated attempts to turn it on. During dive, attempts were made to obtain a sonagram of the transponder in the water column. It may be gone, or just dead.

3. The elevator failed and had to be reset during some turns at the ends of the side-scan sonar lanes and during some go command runs. This is a still-unresolved problem associated with transit maneuvers.

4. A basic program was written for use on the Compaq computer to determine the vector back to the SLS lane from a contact that has been surveyed and evaluated. This was used successfully during contact evaluations.

TEST DATA

Vehicle hour meter times: xxx.x–yyy.y=z.z hours (broken)
Total Amp-Hr.:145
EARS Launch time:0828
AUSS Launch time:0934
Current Meter recovery time:1000
AUSS Recovery Time:1950
EARS Recovery Time:2012
AUSS Descent Time:22min
Total AUSS Bottom Time:9 hrs. 5 min.
Down Time (bottom time not able to operate for any reason): No vehicle resets. Sensor processor reset during contact evaluation of first target.

OBJECTIVES MET

Stated (by priority listed above):

1. Current direction was determined using the fish-cycle. The first search pattern was oriented parallel to the current (east/west). A three-lane, 400-meter-range scale, side-looking search pattern was initiated flying at an altitude of 60 feet (due to Doppler

sonar altitude limitation). The advance speed was 2 knots, which was done in part to obtain the best Doppler performance possible. The navigation stops at the ends of the lanes were eliminated so the vehicle could continue to travel at high enough speeds to provide the best possible Doppler sonar performance.

The plan layout of the square-wave pattern mosaic run covered an area of 2500 feet on a side using a lane coverage of 150 percent. This means that we attempted 800-meter-wide lanes that overlapped previous 800-meter-wide lanes by 200 meters. This overlap was used primarily to compensate for errors expected from the Doppler navigation. Data are being reduced to determined if there were any holidays in the lane coverage.

We detected 3 automobile targets for which immediate contact evaluation was accomplished. In a post-search study of the area, it was revealed that one target in the area was missed. There was excessive noise on the sonagrams when passing near this target. Further analysis is being done on this.

The SLS sonagrams were generated using higher-resolution, 4-bit, auto-tuned signals. These were transmitted at 4800 bps (thanks to the AL Doppler correction system). The Doppler information is stored in flight recorder files, and records were kept of all fish-cycle fixes taken. The fish-cycle fixes were taken at points on the lanes where the SLS detected a target, where targets were evaluated, and at ends of lanes when possible.

Table 1. Contact evaluation statistics.

TARGET	RANGE FROM LANE	TIME TO EVALUATE (time it took to identify target after detection)	TOTAL CONTACT EVALUATION TIME (time it took to transit to target from lane, evaluate target, return to lane, and resume search)
1	75 m	37 min	62 min
2	300 m	26 min	37 min
3	500 ft	31 min	39 min

After completing the E/W runs, we started on a N/S pattern. We went after the first target contact we found (which was very weak) and experienced a low-battery cell before we could identify the target.

2. Realtime acoustic-link Doppler corrector allowed us to operate a reliable acoustic link and operate the side-looking sonar and forward-looking sonar transmitting at 4800

bps. This allowed us to travel at a higher advance speed, and therefore a higher area search rate.

3. Fish-cycle was used successfully throughout the day to conduct the search demonstrations. The separate transducer and amplifier made this operation much easier than it would have been with the previous configuration.

4. Current meter recovered.

Unstated:

1. Proved that scrambler system does not improve acoustic-link performance.

FUTURE TESTS/TASKS IDENTIFIED

1. Cut down all ascent weights to 66.5 pounds — Rutkowski
2. Repair failed Honeywell card — Rutkowski
3. Repair Loran system — Osborne
4. Implement SLS equal duty cycle time synchronization software — Watson
5. Fix problems with recorder and triggers in SLS and FLS — Watson/Rasmussen
6. Compute SeaTrac coordinate position of Del Mar Mini Ranger station using three range information as opposed to SeaTrac calculated coordinates — Watson/Uhrich
7. Research potential obstacle-avoidance transducers and circuitry — Watson/McCracken
8. Troubleshoot problem with SLS not turning off during SLS mosaic runs while in turns — McCracken/Watson
9. Locate spare pitch sensor — McCracken/Walton
10. Include resume function in delivery system. This allows a single command to return to a search lane after a contact evaluation — McCracken
11. Fix time sync problem between main processor and flight recorder — McCracken
12. Document trick procedure for flopping Mini-Ranger baseline for SeaTrac — McCracken
13. Improve vehicle compass/Zendex interface — Mackelburg
14. Install permanent voltage and frequency meters on input to UPS — Mackelburg

15. Provide on-board DOS manual — Osborne
16. Modify "belly-band" installation shim — Burton/Walton
17. Obtain sonar data from vehicle video recorder — Grace

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*

In FY 1987, tests were conducted with the Advanced Unmanned Search System (AUSS) vehicle to define and solve technical and performance-risk areas. This report describes these FY 1987 AUSS sea tests, including the modifications and improvements, made to collect data needed to support the next-generation system design. This report covers the most critical risk areas that were encountered in the FY 1987 sea tests. The areas covered included acoustic link, acoustic tracking, vehicle navigation, vehicle control, obstacle avoidance, search sensors, and system computers.

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	16. PRICE CODE

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